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# THE BLACKWELL ENCYCLOPEDIA OF MANAGEMENT

SECOND EDITION

# OPERATIONS MANAGEMENT

*Edited by*

NIGEL SLACK
AND MICHAEL LEWIS

Blackwell Publishing

THE BLACKWELL ENCYCLOPEDIC DICTIONARY

# OPERATIONS MANAGEMENT

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*Edited by*
Nigel Slack and
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*University of Warwick and*
*University of Bath*

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# Contents

# Preface

Operations management (OM) is the set of activities in any organization that are concerned with the resources devoted to the production and delivery of products and services. Every organization has an operations function because every organization produces some type of products and/or services, although they call the operations function by this name. This definition encompasses service and manufacturing as well as for profit and not for profit organizations. OM is also ubiquitous. Every thing we wear, eat, sit on, use, read, or knock about on the sports field has been produced. So has every book we borrow from the library, every treatment we receive at the hospital, every service we expect, and every lecture we attend. Moreover items were produced before they were sold in an organized manner, or before their cost was precisely calculated. OM is arguably the oldest of management disciplines.

It is also a discipline profoundly influenced by practice. Unlike some management functions, the OM task is principally defined by the pragmatic challenges of immediacy. In other words, the day to day production of goods or delivery of services requires practitioners to continually make decisions and implement changes. Academic OM also tends to focus on "real" managerial preoccupations and regularly re dedicates itself to the needs of practitioners. Unfortunately, whilst this concern with relevance is entirely laudable, it may have rendered the discipline somewhat blinded to its rich and extended heritage. Moreover, the theoretical underpinnings of the OM field are somewhat different from other academic management subjects like strategy, marketing, or finance. Whereas these fields of study are more or less directly connected to base theoretical disciplines such as economics, sociology, psychology, and mathematics, OM's underpinnings are more fragmented.

The specific genealogy of "modern" OM is a curious amalgam of very different academic and practical disciplines (e.g. economics and engineering) and as a result the title Operations Management has emerged only after several changes. If this encyclopedia had been compiled at another point in time, then the title might have been Production and Operations Management or Manufacturing Management, or even Industrial Engineering. In part, this is a consequence of bearing a "functional" name; because organizational labels inevitably evolve over time (e.g. personnel becoming human resources). However, it also reflects some of the profound shifts that have taken place in the underlying pre occupations of the discipline.

Understanding the nature of "modern" OM means tracing its influences from the seminal descrip tion of pin making and articulation of the concept of the division of labour in Smith's *Wealth of Nations* in 1776. Likewise Babbage in 1832 built upon Smith's work, and is often cited as a key influence on OM. However, it was not until Frederick Winslow Taylor (1856–1915) sought to establish a "science" of operational management based upon the "scientific" selection of workers and their scientific education and development, that OM theory had any impact upon practice. Until him no one generated the sustained interest and systematic framework that was necessary to proclaim management as a discipline. Taylor was always an extremely controversial figure, even during his own lifetime, and his philosophy was (and still is) widely caricatured. However an objective appraisal of Taylor's core concepts demonstrates how many of the principles he espoused are now widely accepted.

The earliest OM ideas emerged in the UK but their further development and widespread accept ance happened in North America. This is no coincidence. The UK's industrial revolution began in the textile industry during the eighteenth century, stimulated by coincidental geo political (a rapidly growing empire, centred around India) and technological events. By the mid nineteenth century, however, an alternative system of manufacturing was emerging in the United States. During this period the US saw the first widespread introduction of interchangeable parts that allowed manufac turers to break more fundamentally with the craft model of production and fully exploit the division of labor, most notably in the practices implemented by Henry Ford (1863–1947). Ford carefully detailed his approach to manufacturing in two books and although he built his factories upon basic American manufacturing principles, he was the first to produce very complex products. In addition to his extraordinary attention to the detailed design and control of various production processes, he also understood the more strategic financial and operational significance of cycle time and throughput in manufacturing. Like Taylor (of whom he apparently knew nothing!), Ford's ideas were viewed as extremely important and proved highly influential in the development of the Japanese production concepts that would be so influential more than half a century later.

At about the same time that Taylor was working and writing, a marketplace was emerging (particularly in North America) for formal management education, and scientific management formed a key component of many curricula. Similarly, engineering education was broadening to include industrial engineering courses, also strongly influenced by scientific management principles. By the 1950s, the scope of academic OM as a descriptive field had become very broad (including personnel management, accounts, general management etc.). This led to curricula being dismantled into separate functional fields, which left the "parent" OM discipline with relatively few natural issues to develop. In response, OM began to incorporate the quantitative modelling techniques developed by Operations Research/Management Science (ORMS) practitioners and academics. OM's relationship with ORMS remains extremely close while at the same time dealing with the broader managerial implications of operations decisions.

OM had developed up to this point with an almost exclusive manufacturing focus. The growth of the "service imperative" has begun to change this, under the influence of two key factors. The first of these is recognition that the service level of how goods are delivered to the customer and how the customer is treated can provide many manufacturing organizations with a competitive edge. The second reason is that manufacturing accounts for a smaller and smaller proportion of GDP in most Western economies. There are clear limits to the direct applicability of manufacturing concepts to service however, and in particular, traditional OM lacked any conceptualization of transactions directly involving the customer.

Meanwhile Japanese industrial development (especially in the automotive industry) was following a very different trajectory. The embodiment of this was the Toyota Production System that can be summarized as an adherence to two key principles. The first of these is an emphasis on planning and control driven by customer pull rather than organization push. Such systems seek to prioritize WIP reduction over capacity utilization (compare this with a classic line balance approach) and are enabled by (and/or necessitate) production smoothing, quick set up times and stages closely inter connected by kanbans. The second key principle is a commitment to continuous improvement enabled by people development. The practical implementation of this apparently straightforward principle is much more challenging. From a critical perspective, its effects upon the workforce (it often requires de unioniza tion or single union agreements) have been attacked and, more managerially, the demands placed upon workers by lean systems have been highlighted as a problem with respect to ongoing staff recruitment. These Japanese "Lean Production" practices aroused intense interest. The enhanced productivity that resulted from its adoption has universal appeal. Indeed Lean Production's originators, by formulating the operating problem as an unceasing battle against waste were able to make it seem almost axiomatic that lean implied better. Although the Lean Production concept was initially viewed as a counter intuitive alternative to traditional manufacturing models, today it is arguably the paradigm for manufacturing operations.

It was the impact of lean production ideas, together with other developments such as total quality management (TQM) and business process redesign (BPR) that saw the beginning of an OM renaissance in the early 1980s. By the mid 1990s the discipline was once again firmly located in both the academic and practitioner mainstreams. There are a number of explanations for this that add to the cumulative effect of successful operations practices.

- No other functional area has such a direct impact on both revenue and cost. The popularization of ideas such as TQM and lean production established in both practitioner and research arenas the idea that operations practice must pursue the twin objectives (even if to different extents) of improving aspects of service such as quality, variety, responsiveness etc., while at the same time reducing costs. Given the business maxim that "profit is a very small number made up of the difference between two very big numbers," any subject that claims to increase revenue *and* reduce costs must demand the attention of companies that can appreciate its potentially disproportionate effect on profitability.
- All types of services (including "internal" services such as HR) have become more concerned about their levels of productivity, quality, responsiveness, etc. As a result, the audiences for process management and reengineering courses, books, and consultancy, are no longer limited to functional operations managers. Increasingly, all sorts of administrative personnel and managers see themselves as managing processes and therefore have something to learn from operations management ideas.
- Interest in OM has paralleled the growth of interest in resource based or capability based models of competitive strategy. The overlaps between operations management/strategy and resource based driven views of general strategy are often explicit. Prahalad and Hamel ("The core compe tence of the corporation", *Harvard Business Review*, May–June, 1990), for example, defined their core competencies as "collective learning . . . especially how to co ordinate diverse production skills and integrate multiple streams of technologies."

Over the last two centuries OM has emerged a powerful lens through which it is possible to understand and improve the operational and strategic activities of nearly all organizations. It is likely that it will continue to develop along a trajectory defined by its blend of theoretical influences and practical insight. Predicting the future of any discipline is of course a risky (and often futile) exercise. However, some trends may be already discernible. The dominant forces, that have shaped its development over the last century, may continue to shape its future. There will be some who emphasize conceptual rigour and the development of scientific insight, whereas others will express concerns over a drift away from practical relevance, and a call to re establish the discipline using practitioner needs as a guide. In the short/medium term, it seems likely that more integrative and strategic themes will continue to grow in significance. This creates the danger that this will be followed by another period of hollowing out of the core field. Indeed there may be evidence of this happening with respect to issues such as supply chain management, product development, and e business. If OM continues to explore more intangible service operations and address broader strategic issues, a trend accentuated by market demands for more strategic and service exemplars (and less quantitative studies), many of its traditional methodologies and theoretical antecedents could appear increasingly inappropriate.

*Nigel Slack and Michael Lewis*

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# A

## activity-based costing

*Ken Bates*

Activity based costing (ABC) focuses management's attention on the underlying causes of costs. Activities cause costs, and products only incur costs through the activities they require, such as design, manufacture, engineering, marketing, delivery, invoicing, cash collection, and after sales service. The mechanics of the ABC approach are as follows:

- Identify the main activities that are consuming resources.
- Determine the cost driver for each major activity.
- Collect the costs of each activity and divide by the cost driver volume to determine a burden rate.
- Use this rate to trace activity costs to products according to the individual product's demand for that activity.

The resultant product costs should be a fair representation of each product's consumption of the company's resources, and hence a critical input to pricing and product mix decisions.

The costs of production support activities, such as production scheduling, setup, inspection, and material handling, were previously considered to be "fixed costs," but ABC reclassifies them as "long term variable costs." This enhances managers' understanding of cost behavior, enabling them to more accurately trace costs to products and therefore to exercise greater cost control. The conventional approach of absorbing overheads on direct labor hours or machine hours will be inappropriate for tracing most long term variable costs to products. The volume of work undertaken in production support departments will not depend on the volume of output alone. The greater the number of different products produced, the more production scheduling activity and the greater the demand for setups and inspections. If more complex products are produced, the number of components rises and the demand for materials handling increases. It is clearly the diversity of the product range and the complexity of the production process that cause extra demand for support activities, and support department costs are driven by complexity and diversity not by production volumes.

ABC is likely to benefit complex organizations with diverse product or service portfolios. There are costs associated with implementing and running a new and more complex costing system and identification of appropriate cost drivers is not an easy task. Some ABC systems have floundered because of poor definition of activities and cost drivers, others due to over sophistication or lack of commitment. However, many ABC implementations have provided companies with valuable information to help them compete in an increasingly hostile marketplace. The main benefits of ABC are:

1. ABC provides more accurate product costs and hence reduces the possibility of managers making poor decisions. Accurate product costs are particularly important when a firm faces fierce competition.
2. ABC reveals the costs associated with producing a diverse product portfolio and hence identifies the need to either reduce the variety of products offered or investigate operational improvements to reduce these costs. ABC can help monitor "continuous improvement" initiatives as it provides

measures (e.g., cost per setup) against which to monitor performance.

3 By increasing the accuracy of reported prod uct costs, ABC reduces the need for special studies to obtain decision relevant informa tion. For example, if there is a proposal that will reduce setup times, managers can use ABC information to estimate potential cost reduction.

ABC methodology is the foundation for cus tomer profitability analysis, activity based cost management, and activity based budgeting.

See also *cost; planning and control in operations; productivity; project cost management and control*

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### add/delete bill of materials

*Pamela Danese*

The add/delete bill of material defines a special product in terms of a standard product, specify ing which components need to be added and which components need to be removed. For example, if a company defines a standard product including the components A, B, C, and D, when the company receives a customer order specify ing product characteristics it can configure the required product by identifying its differences from the standard product. For instance, the required product can be obtained by eliminating from the standard product component A and adding components E and F. The add/delete bill of material is utilized not in elaborating fore casts but in the phase of order generation.

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### advanced manufacturing technology

*Michael Lewis*

Advanced manufacturing technology (AMT) is a generic label for the application of information technology (IT) to manufacturing process tech nology applications. The notion that IT equals "advanced" helps locate the origins of the ter minology in the 1970s and 1980s. AMTs have attracted substantial operations management (OM) research interest, in particular since the widespread adoption of robots and other hardware/software components (e.g., AGVs, MRPII) promised to create the "factory of the future" (*see* AUTOMATED GUIDED VEHICLES; MANUFACTURING RESOURCES PLANNING). After the hyperbole, however, many authors have subsequently argued that AMT failed to live up to its promise. After accepting that suc cessful adoption was actually very difficult and involved much more than adherence to a plan, researchers became more interested in the broader "process that leads to the successful adoption of an innovative new technology" (Voss, 1988: 56).

See also *computer integrated manufacturing; human centered CIM; implementing process tech nology; innovations in service companies; process technology; robotics*

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## aesthetics (product)

*James Moultrie*

Industrial goods and products are normally designed in order to offer some functional bene fit, but the way a product looks can have a significant impact on consumer perceptions and consequently market response. Thus, the aesthetics of a product are a subject of increasing interest to all product designers and operations managers. The term itself is derived from the Greek *aisthçetikos*, but unfortunately, although the subject of beauty has been debated for many centuries, there is no unanimity on what is beau tiful or what comprises a beautiful artifact. Some early scholars held the view that beauty was an objective (almost measurable) property of an artifact: certain lines, shapes, and color combin ations were believed to be inherently attractive and each object had an "ideal form" which would be considered attractive by all. This notion is exemplified by the continued usage of aesthetic rules established in Greek architecture such as the "golden section" and the adherence to strict geometric rules. A similar approach applied to product design was pioneered by the Bauhaus school in Germany in the 1920s. Through the application of "Gestalt rules" (symmetry, continuance, repetition and har mony, etc.), Bauhaus products were highly rational and satisfied a desire for order and simplicity (i.e., Modernism).

Today, the cultural and economic fragmenta tion created by a range of historical and technical factors means that differences in judgments and preferences make it difficult to believe in univer sal aesthetic principles. As such, the ideals and standards to which one culture aspires may not be appreciated by other cultures. This notion of "cultural taste" indicates that objective proper ties of a design are insufficient in themselves to explain judgments of attractiveness. At the same time, aesthetics become even more important as the same factors have also imbued products with a range of socially determined symbolic mean ings. This culturally agreed meaning allows consumers to communicate their identity through objects (and brands, etc.). In summary, a product's appearance provides crucial infor mation about its apparent purpose, mode of op eration, and perceived qualities. In practice, aesthetic judgments are influenced by the com bination of a product's perceived "attractive ness," the social or symbolic values it may reflect, and broader interpretations of its pur pose and mode of use.

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## aggregate capacity management

*Nigel Slack*

Aggregate capacity management is the activity of setting the capacity levels of an organization in the medium term. The important characteristic of capacity management here is that it is con cerned with capacity measured *in aggregated terms*. Thus aggregate plans assume that the *mix* of different products and services will remain relatively constant during the planning period.

Typically, in aggregate capacity management, operations managers are faced with a forecast of demand which is unlikely to be either certain or constant. They will also have some idea of their own ability to meet this demand. Nevertheless, before any further decisions are taken they must have quantitative data on both capacity and demand. So step one will be to *measure the ag gregate demand and capacity* levels for the plan ning period. The second step will be to *identify the alternative capacity plans* that could be adopted in response to the demand fluctuations.

The third step will be to *choose the most appropri ate capacity plan* for their circumstances.

### Measuring Demand and Capacity

Demand forecasting is a major input into the capacity management decision. As far as capacity management is concerned, there are three re quirements from a demand forecast. First, that it is expressed in terms that are useful for cap acity management, which means it should give an indication of the demands that will be placed on an operation's capacity, and expressed in the same units as the capacity. Second, that it is as accurate as possible. Third, that it should give an indication of relative uncertainty, so that oper ations managers can make a judgment between, at one extreme, plans that would virtually guar antee the operation's ability to meet actual demand, and, at the other, plans that minimize costs.

In many organizations aggregate capacity management is concerned largely with coping with seasonal demand fluctuations. Almost all products and services have some *seasonality of demand* and some also have *seasonality of supply*.

### The Alternative Capacity plans

There are three "pure" options for coping with supply or demand variation.

- Ignore the fluctuations and keep activity levels constant (level capacity plan).
- Adjust capacity to reflect the fluctuations in demand (chase demand plan).
- Attempt to change demand to fit capacity availability (demand management).

In practice most organizations will use a mixture of all of these "pure" plans, although often one plan might dominate.

In a level capacity plan, the processing cap acity is set at a uniform level throughout the planning period, regardless of the fluctuations in forecast demand. This means that the same number of staff operate the same processes and should therefore be capable of producing the same aggregate output in each period. Where non perishable materials are processed, but not immediately sold, they can be transferred to finished goods inventory in anticipation of sales at a later time period. This can provide stable employment patterns, high process utilization, and usually also high PRODUCTIVITY with low unit costs. Unfortunately, it can also create considerable inventory. Neither are such plans suitable for "perishable" products, prod ucts which are tailor made against specific customer requirements, or products susceptible to obsolescence.

Very high under utilization levels can make level capacity plans prohibitively expensive in many service operations, but may be considered appropriate where the opportunity costs of indi vidual lost sales are very high, for example, in high margin retailing. It is also possible to set the capacity somewhat below the forecast peak demand level in order to reduce the degree of under utilization. However, in the periods where demand is expected to exceed planned capacity, customer service may deteriorate.

The opposite of a level capacity plan is one which attempts to match capacity closely to the varying levels of forecast demand. Such pure "chase" demand plans may not appeal to operations which manufacture standard, non perishable products. A pure chase demand plan is more usually adopted by operations which cannot store their output, such as service oper ations or manufacturers of perishable products. Where output can be stored, the chase demand policy might be adopted in order to minimize or eliminate finished goods inventory.

The chase demand approach requires that capacity is adjusted by some means. There are a number of different methods of achieving this, although all may not be feasible for all types of operation.

*Overtime and idle time.* Often the quickest and most convenient method of adjusting capacity is by varying the number of productive hours worked by the staff in the operation. The costs associated with this method are overtime, or in the case of idle time, the costs of paying staff who are not engaged in direct productive work.

*Varying the size of the workforce.* If capacity is largely governed by workforce size, one way to adjust capacity is to adjust the size of the work force. This is done by hiring extra staff during periods of high demand and laying them off as demand falls. However, there are cost implica tions, and possibly also ethical ones, to be taken into account before adopting such a method. The costs of hiring extra staff include those associated with recruitment as well as the costs of low productivity while new staff go through the learning curve (*see* LEARNING CURVES). The costs of layoff may include possible sever ance payments, but might also include the loss of morale in the operation and loss of goodwill in the local labor market.

*Using part time staff.* A variation on the previ ous strategy is to recruit staff on a part time basis, i.e., for less than the normal working day. This method is extensively used in service oper ations such as supermarkets and fast food res taurants but is also used by some manufacturers to staff an evening shift after the normal working day. However, if the fixed costs of employment for each employee, irrespective of how long they work, are high, then using this method may not be worthwhile.

*Subcontracting.* In periods of high demand an operation might buy capacity from other organ izations. Again, though, there are costs associ ated with this method. The most obvious one is that subcontracting can be expensive because of the subcontractor's margin. Nor may a subcon tractor be as motivated to deliver on time or to the desired levels of quality.

Many organizations have recognized the benefits of attempting to *manage demand* in vari ous ways. The objective is to transfer customer demand from peak periods to quiet periods. This is usually beyond the immediate responsibility of operations managers, whose primary role is to identify and evaluate the benefits of demand management, and to insure that the resulting changes in demand can be satisfactorily met by the operations system. One method of managing demand is to *change demand* by altering part of the "marketing mix," such as by changing prices or promotional activities to make it more attract ive in off peak periods. A more radical policy may be to create *alternative products or services* to fill capacity in quiet periods.

### Choosing an Aggregate Capacity Management Approach

An operation must be aware of the consequences of adopting each plan. For example, a manufac turer, given an idea of its current capacity and given a demand forecast, must calculate the effect of setting its output rate at a particular level. A method that is frequently cited as helping to assess the consequences of adapting capacity plans is the use of cumulative represen tations of demand and capacity. The most useful consequence of this is that, by plotting capacity on a cumulative graph, the feasibility and conse quences of a capacity plan can be assessed. Some impression of the inventory implications can also be gained from a cumulative representation by judging the area between the cumulative pro duction and demand curves. This represents the amount of inventory carried over the period.

The cumulative representation approach suc ceeds in indicating where operations managers can plan to provide the appropriate level of cap acity required at points of time in the future. However, in practice, the management of cap acity is a far more dynamic process that involves controlling and reacting to *actual* demand and *actual* capacity as it occurs. This aggregate cap acity control process can be seen as a sequence of partially reactive capacity decision processes.

See also *bottlenecks; capacity strategy; inventory management; overall equipment effectiveness*

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## analytical estimating

*John Heap*

Analytical estimating is a structured, estimating technique, often used in WORK MEASURE

MENT, in which a task is analyzed into its basic component operations or elements. Standard times, where available from another source, are applied to these elements. Times are applied to the remainder, where no prior data are available, by estimating based on experience of the work under consideration. The estimating is carried out by a skilled and experienced worker who has had additional training in the process of estimat ing and who simply estimates the time that would be required by a fully competent and experienced worker, working at a defined level of performance. The analysis into elements is a key factor in producing reliable times, since, while time estimates for individual elements may be "inaccurate," any errors are random and will compensate for one another. Addition ally, since the technique is normally used for assessing workloads over a reasonably long plan ning period, errors in individual tasks will also cancel each other out.

See also *predetermined motion time systems; time study; work measurement; work study; work time distributions*

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## anthropometric data

*John Heap*

Anthropometric data are data that relate to people's size, shape, and other physical abilities, used in the design of jobs and physical facilities, usually classified by gender and age. They are typically expressed in percentile terms. Anthro pometric data are used in the analysis of work, support ergonomic workplace design at a high level of detail, and may include analysis down to the level of operator motion patterns. For example, the design of controls, warning, and safety devices must insure their rapid and effect ive use. The design of the workplace should promote, and certainly not hinder, safe ways of working and should take place alongside ergo nomic work environment design. Anthropomet ric data are also extensively used in product and service design to specify sizing.

See also *ergonomics; method study*

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## automated guided vehicles

*Nigel Slack*

Automated guided vehicles (AGVs) are small, independently powered vehicles that move ma terials to and from value adding operations. They can be guided by cables buried in the floor of the operation and receive instructions from a central computer. Variations on this arrangement include AGVs which have their own on board computers or optical guidance systems. In addition to any cost advantages gained by substituting labor with technology, the use of AGVs can help promote just in time delivery of parts between stages in the produc tion process (*see* JUST IN TIME). In some industries they are also used as mobile worksta tions to replace the more traditional conveyor systems; for example, truck engines can be assembled on AGVs, with the AGV moving between assembly stations. The ability to move independently reduces the pacing effect on each stage in the process and allows for variation in the time each stage takes to perform its task. AGVs are also used to move materials in non manufacturing operations such as ware housing, libraries, offices, hospitals, and some restaurants.

See also *advanced manufacturing technology; computer integrated manufacturing; flexible manufacturing system; process technology; robotics*

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# B

## balancing loss

*David Bennett*

Balancing loss is the quantification of the lack of balance in a production line, defined as the percentage of time not used for productive purposes with the total time invested in making a product. The importance of this measure lies in its ability to assess perhaps the most problematic of all the detailed design decisions in product layout, namely that of LINE BALANCING. Achieving a perfectly balanced allocation of activities to workstations is nearly always impossible in practice and some imbalance in the work allocation between stages results. So the effectiveness of the line balancing activity can be measured by balancing loss. In effect it is the time wasted through the unequal allocation of work.

See also *bottlenecks; business process redesign; layout; process layout*

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## beer distribution game

*Arne Ziegenbein and Joerg Nienhaus*

The beer distribution game is a simulation of a supply chain. Participants take the role of a company and decide – based on their current stock situation and customer orders – how much to order from their suppliers. The goal is to minimize costs for capital employed in stocks while avoiding out of stock situations. The simulation explains inefficiencies of supply chains known as the bullwhip effect.

See also *supply chain dynamics; supply chain management; supply network information systems*

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## benchmarking

*Nick Oliver*

Benchmarking first arrived on the management scene in the late 1980s. The first book specifically about benchmarking was Camp's *Benchmarking: The Search for Industry Best Practices*, which was published in 1989. As with any relatively recent phenomenon, particularly in the field of management, there has been extensive discussion as to whether benchmarking represents a passing fad or is destined to become an established practice in the long term. A search on the management database *ProQuest Direct*, undertaken in early 2000, resulted in 2,256 hits, and demonstrated a massive rise in interest in benchmarking between 1990 and 1992.

Since peaking in the early 1990s, interest in benchmarking appears to have been sustained, and articles have appeared on how and how not to benchmark and the benefits and costs of benchmarking. These have covered many differ ent sectors, including manufacturing, product development, logistics, healthcare, education, plant maintenance, customer satisfaction, as well as many others. Significantly, the vast ma jority of these articles are short (typically one or two pages) and appear predominantly in practitioner journals. Although a number of large scale benchmarking studies have been published, most benchmarking activity has occurred outside the public domain, undertaken by practitioners for practitioners.

This entry addresses four main issues: (1) What is benchmarking and how widespread is the practice? (2) What techniques of and ap proaches to benchmarking exist? (3) What public domain examples of benchmarking studies exist and what can be learned from them? (4) What assumptions underpin the benchmarking pro cess and what criticisms may be leveled against it?

## Benchmarking Defined

Several definitions of benchmarking exist, the vast majority of which possess the same basic themes: "Benchmarking is the continuous pro cess of measuring products, services and prac tices against the toughest competitors or those companies recognized as industry leaders" (Camp, 1989: 10); "Benchmarking is a continu ous search for and application of significantly better practices that lead to superior perfor mance" (Watson, 1993: 4); "Benchmarking is the process of comparing business practices and performance levels between companies (or divisions) in order to gain new insights and to identify opportunities for making improve ments" (Coopers and Lybrand/CBI, 1994: 3).

The key elements of benchmarking are simple: at its core, benchmarking is about sys tematically comparing the performance of oper ations with a view to stimulating performance improvement – either from the "shock value" of the comparison or from the extraction of the principles of best practice from high(er) performing operations. It is this combination of identifying differentials in performance or pro cesses and then *using* this information to leverage improvement, learning, and change which best characterizes benchmarking. Significantly, this also confers on benchmarking a political dimen sion.

Camp (1989) identifies four types of bench marking:

1 benchmarking against internal operations;
2 benchmarking against external operations of direct competitors;
3 benchmarking against the equivalent func tional operations of non competitors;
4 generic process benchmarking.

These approaches all involve comparison of the performance and management of processes. One could add a fifth category of product benchmarking, which compares the features and performance of products. For example, car manufacturers routinely carry out "tear down" analyses of competitor's vehicles to see how they compare in terms of design, manufacturability, and other features. The focus in this entry is on benchmarking as process, not product, comparison.

Internal benchmarking, as the name suggests, refers to the comparison of processes within the same organization. It is most likely to be found in large multidivisional or international firms where subunits have comparable operations. Examples might include comparisons in assem bly hours per car or assembly defects per vehicle between different car assembly plants within a multinational car company. This raises the ques tion of the differences between the collection of information for benchmarking purposes versus normal operational control purposes. In theory, the distinction is clear – benchmarking is under taken as a one off exercise, for the purpose of learning and improvement, rather than control. In practice, benchmarking studies are inevitably likely to function as occasions for apportioning glory – or blame – and therefore may have a profoundly political dimension. For example, Delbridge, Lowe, and Oliver (1995) describe how the findings of a benchmarking study were used by a plant director to publicly criticize his managers for the poor performance of the plant. Lack of cooperation from the operating units whose performance is to be benchmarked is a common problem in internal studies for this very reason.

"Competitor benchmarking," as the name suggests, involves performance comparisons be tween organizations which are direct competi tors. The logic behind this is clear; if firms are operating in exactly the same marketplace, then, in theory at least, many issues of compar ability should be overcome. This is relevant as the biggest single challenge of benchmarking lies in establishing the *legitimacy* of the compari son. Clearly, if all the comparison reveals is that apples are different from oranges, then little of value has been learned. Delbridge et al. (1995) describe the difficulty in attaining comparability between units on measures of physical productivity and document how this was achieved in a benchmarking study in the automotive industry.

Some competitor comparisons are possible from public sources, for example, company ac counts, but these are generally of limited detail and hence of limited utility. Direct competitor benchmarking can be difficult to carry out owing to the commercial sensitivity of much of the information. However, examples of this do exist, typically where the benchmarking has been carried out by trusted and independent third parties, as for example in the INTER NATIONAL MOTOR VEHICLE PROGRAM (IMVP) (Womack, Jones, and Roos, 1990).

"Functional" or "generic" benchmarking refers to the comparison of specific processes (functions) between organizations whose overall mission or operations may be very different. Camp (1989) gives the example of Xerox's use of L. L. Bean as a benchmark against which to judge the performance of its own dis tribution operation (data from this are shown in table 1.)

**Table 1** Warehouse performance: L. L. Bean vs. Xerox

| | *L. L. Bean* | *Xerox* |
|---|---|---|
| Orders per person day | 69 | 27 |
| Lines per person day | 132 | 129 |
| Pieces per person day | 132 | 616 |

The rationale behind studies such as the Xerox/L. L. Bean exercise is that it is as import ant to understand the processes which generate outputs as to quantify the outputs themselves. The quest is for models of good practice in core business functions – models which may be inde pendent of specific products or services. Bench marking is one method of unearthing such models and revealing any deficiencies in con temporary practice. Activities such as business process reengineering may then build on this knowledge.

There is currently widespread interest in benchmarking. However, it is difficult to assess precisely the extent to which this interest is being translated into actual benchmarking activ ity. One indicator is that several companies have set up units specifically to carry out benchmark ing. A study of benchmarking among the *Times 1000* UK companies carried out by Coopers and Lybrand and the Confederation of British In dustry (CBI) in 1994 concluded that 78 percent of companies were engaged in benchmarking. Manufacturing companies were more likely to carry out benchmarking studies than were ser vice companies. Benchmarking was found across all business functions, but its use was highest in customer service, sales, and logistics and lowest in the less tangible area of product development and research and development.

The Coopers and Lybrand/CBI study noted that the majority of organizations that had en gaged in benchmarking had found it to be a successful exercise, and reported that the main benefits were: assistance in setting meaningful and realistic targets; improvement in productiv ity; gaining of insights into new or different approaches; and motivating employees by dem onstrating what was achievable. The main prob lems reported in benchmarking were: difficulty in gaining access to confidential information, especially information concerning competitors; the lack of resources; and problems in establish ing the comparability of data from different or ganizations. These difficulties notwithstanding, a sizable majority of companies predicted that they would expand their benchmarking pro grams in the next five years.

### The Benchmarking Process

Virtually all the available books specifically about benchmarking are aimed at practitioners and hence emphasize "how to benchmark" or "the process of benchmarking." Although the terminology of these models varies, the prin ciples are similar, involving a series of stages through which the would be benchmarkers should pass. The stages shown in table 2 are drawn from Camp (1989) and are typical of those found in many texts.

An illustration of this approach in action is provided by Lucas Industries, the UK based engineering firm, which has interests in the aero space and automotive industries. In the early 1980s Lucas was faced with its first ever loss in over 100 years of trading. In the words of its chairman, Lucas had to face up to the fact that its "overall performance in most of its major markets had become fundamentally uncompeti tive" (Vliet, 1986: 21). At this point Lucas began a radical program of reform. Financial responsi bility was focused into business units and each unit was required to submit a competitiveness achievement plan (CAP) to Lucas Corporate Headquarters on an annual basis. The CAP was a plan for the achievement of performance levels comparable with the leading international com petitor in the area. Business units that did not institute CAPs risked being closed or sold and during the 1980s over 40 were disposed of. Vliet (1986: 21) characterizes the process as a combin ation of "vigorous decentralization with an active program of measuring up."

**Table 2** The process of benchmarking

| | |
|---|---|
| Planning | • Identifying what processes to benchmark<br>• Identifying organizations to benchmark against<br>• Establishing sources of data and collection methods |
| Analysis | • Establishing the gap between top benchmarks and own performance |
| Communication | • Disseminating the findings of the benchmarking process |
| Action | • Development of performance goals and targets<br>• Development of plans to achieve performance goals |

This approach clearly embodies several of the stages of the benchmarking process identified by Camp and others. The trigger to action is the establishment of a gap between existing per formance and competitor performance, which in turn feeds into a series of actions designed to close the gap (JUST IN TIME principles, qual ity improvement, and so on). It is interesting to note that the agenda behind the Lucas approach was stimulating change and improvement in re sponse to a rapidly deteriorating situation; the function of benchmarking appeared to be to kick start the process of change by providing substantial and unassailable proof of the need to improve. However, the Lucas case also dem onstrates that actions which demonstrate the need for change cannot of themselves overcome long term historical and structural issues. In the late 1990s Lucas was forced to merge with the Varity Group, a move that was widely seen as a takeover of the former by the latter. The merged group was taken over again, by TRW, in 1999.

### Benchmarking Studies

Benchmarking studies may be divided into two main types. The first are commercial studies undertaken by or on behalf of companies at their own expense and for their own benefit. For obvious reasons, these rarely enter the public domain and so it is difficult to generalize about the extent and sophistication of these studies. The other type of benchmarking study, of which there are several examples, constitutes what might be termed "public domain" research and is typically undertaken by universities and/ or management consultancy firms. The pur poses of this type of benchmarking study are varied but typically involve an academic agenda of investigating the characteristics of high per forming organizations and a consultancy agenda of spreading alarm in order to generate consult ancy work.

One of the earliest and best known examples of benchmarking which is in the public domain is the first IMVP, which was coordinated by MIT. This program aimed to systematically compare the performance of car assembly plants around the world to identify the reasons behind this performance. The program ran from 1985 to 1990 and culminated in the publication of the influential *The Machine That Changed the World* (Womack et al., 1990). This book represents a powerful cocktail of startling statistics (concern ing the superior performance of car assembly plants in Japan vis à vis those in the West) and prescriptions for success (in the form of LEAN PRODUCTION concepts, the main explanation offered for this performance superiority). The impact of this book is a useful illustration of the potential leverage of a benchmarking study. Hundreds of thousands of copies of the book were sold in the five years following publication and many managers, particularly (but not exclu sively) in the automotive industry, took it as the blueprint for achieving high performance manufacturing. The process at work here is two fold: on the one hand there is the shock of a comparison which reveals that one's own organ ization is being massively outperformed by others. In the aftermath of this, people are likely to be very receptive to alternative models (such as lean production), which appear to be tried, tested, and vastly superior.

Other benchmarking studies that are publicly available include studies into the autocompo nents industry (Delbridge et al., 1995) and gen eral manufacturing (IBM Consulting Group, 1993, 1994; Miller, Meyer, and Nakane, 1994). The industry specific studies tend to emphasize precision and comparability of performance and therefore restrict the products covered in order to achieve this. The more general studies (e.g., the IBM Consulting Group studies) attempt to be more generic and tend to use executive self reports as the measure of whether each company is more or less competitive than others in its field, a practice that generates performance data of questionable validity.

### Criticisms of Benchmarking

Benchmarking as a field of activity is insuffi ciently developed to have attracted wide spread comment, but individual benchmarking studies have attracted criticism, particularly the first IMVP study (Williams et al., 1994). Many of the criticisms leveled against this study con cern general issues around the benchmarking process itself, and so it is instructive to examine them.

The first premise on which the IMVP has been attacked lies in its choice of unit of analysis, namely, the individual firm or operating unit; most benchmarking studies focus on this level. Critics point out that this tacitly inflates the importance of some factors and diminishes the significance of others:

> An unconscious politics of managerialism runs through the text: at every stage [in *The Machine That Changed the World*] the company is the unit of analysis and the world is divided into good companies and bad companies with managers as the privileged agents of change who can turn bad companies into good companies. (Williams et al., 1994: 323)

Seen from this perspective, benchmarking tacitly assumes a free market, survival of the fittest position. Efficient and well run com panies survive and prosper, inefficient ones do not. Although the market may be the final arbi ter on performance, benchmarking provides detailed operational indicators of strengths and weaknesses. This may be valid when compari sons are made between units operating in the same markets or economies, but the legitimacy of some comparisons that are made across na tional boundaries can be challenged, because explanations tend to center on the firm and not on the context within which it is embedded. The contrast between the conclusions of the IMVP and those of their critics as to why the Japanese car makers – in particular Toyota – outperform their western counterparts could not be more stark: "We believe that the fundamental ideas of lean production are universally applicable anywhere by anyone" (Womack et al., 1990: 9); "These techniques are a historical response to Toyota's dominance of the Japanese car market which is uniquely non cyclical" (Williams et al., 1994: 352).

The argument here is not that benchmarking inevitably generates data that are *wrong*, but rather that by its very nature it generates data which are *partial* and which may overlook issues of context and market and environmental con straint. In a somewhat different vein, Cox, Mann, and Samson (1997) criticize benchmarking on the grounds that it represents "a mixed metaphor." The language of benchmarking, they argue, is dominated by notions of competition, although the exercise of benchmarking itself requires cooperation. The argument of the Cox et al. paper is itself somewhat confused, but the paper does at least attempt to explore some of the assumptions that lie behind benchmarking – unlike most of what is written about the topic.

It is clear that there is widespread interest in benchmarking among practitioners; this is evidenced by the large number of (expensive) seminars and workshops on benchmarking run by the major consulting firms and by the large volumes of writing on the topic from a practitioner's perspective. Currently most of the material specifically on benchmarking is in the form of "how to do it" documents, although there is academic interest in benchmarking as a tool to identify and explain differences in performance between firms. In this respect benchmarking represents another strand to the empirical, positivist research tradition popular among the ranks of some management researchers. Like so many fashionable management topics, there is little about benchmarking *per se* which is of itself novel – systematic comparisons of performance and processes have been around for decades.

What does appear to be novel is the function that benchmarking is performing. Many benchmarking programs represent specific attempts to bring the "reality" of the outside world within the boundary of the organization and therefore serve to provoke and legitimate change. For this reason, critics have challenged the "unconscious managerialism" that lies behind benchmarking on the grounds that the causes of productivity and other business performance problems are laid squarely on the shoulders of managers, to the neglect of economic and institutional context. This does not of itself negate the value of benchmarking, but it does suggest that some care is necessary in interpreting and acting upon the findings of benchmarking studies, particularly when these span national boundaries.

See also *breakthrough improvement; business excellence model; continuous improvement; total quality management*

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## best practice

*Marek Szwejczewski*

Over the last decade the notion of "best practice" has taken a firm hold in both practitioner discourse and operations management (OM) literature. The term can be defined as "a practice that has been shown to produce superior performance," and correspondingly, the adoption of best practices is viewed as a mechanism for improving the performance of a process, business unit, product, service, or entire organization. If best practices are (tautologic ally?) located within "best in class" organiza tions, the logic is that other firms should learn from them and not rely exclusively on home grown resources and activities. Companies that only look inwards will not be able to learn and benefit from the progress made by others.

The activity of looking for best practice can bring about a greater awareness of the external world. Its value is in learning about practices used by others that are better than those cur rently in place internally. The concentration on uncovering industry best practices is a good route to superior performance. By not focusing solely on the company's own sector, there is a higher likelihood of finding a breakthrough busi ness practice used by the best organizations. Also, the action of looking for industry best practices helps to reduce the impact of "not invented here" syndrome: finding practices already in operation effectively neutralizes the argument that they are not applicable, since a company is implementing what has been shown to work. For a practice to be called "best" it must, of course, produce a positive and signifi cant improvement in performance. The use of the practice should result in a sustainable, rather than transitory or one off, improvement. Also, it should have the potential to be replicated and used by other organizations. A best practice tends to be innovative; it is a new or creative approach, and is associated with progressive or innovative companies (Martin and Beaumont, 1998).

## History of the Concept

The concept of best practice really came to prominence with the rise of the benchmarking movement in the late 1980s. Benchmarking is the search for industry best practices that lead to superior performance (Camp, 1989). It in volves the identification of those companies, ir respective of industry, that have demonstrated superior performance in the area being bench marked. Once the firms have been found, their processes and methods can be examined and the best practice identified. Once identified, these practices can then be used or modified to achieve superior performance. The spread of the idea of benchmarking has helped to raise the profile of the concept of best practice (Voss, 1995). In addition, other factors have helped to increase awareness of the concept. The introduction of various league table and award schemes for high performing companies has had an influ ence: for instance, the US Malcolm Baldrige National Quality Awards, the European Quality Awards, and the Management Today Awards for UK Manufacturing have all highlighted the practices award winning organizations are using (*see* SELF ASSESSMENT MODELS AND QUAL ITY AWARDS). In parallel, the rise of Japanese manufacturing meant that many western com panies became extremely interested in adopting and adapting the practices used by them. The most obvious example of this has been the adop tion by western firms (especially car manufactur ers and component suppliers) of the various practices used by Japanese firms in the automo tive sector. Consultants have also played their part in promoting best practices. Equally, the adoption of best practices has been encouraged by governmental organizations: the UK Depart ment for Trade and Industry, for instance, launched a "Fit for the Future" campaign, run jointly with the Confederation of British Indus try (CBI), as a mechanism for improving the competitiveness of UK manufacturing.

From a more critical standpoint, one of the assumptions that underpin the concept of "best practice" is that there is a single best way to carry out a process or activity. However, given the fact that all practice is to some extent context specific (Davies and Kochhar, 2002), adopters should actively consider whether the practice is in fact appropriate for the intended use (and the differ ent context it will be used in). Similarly, it is important to examine the practice in detail to see what its impact really is. Is there convincing evidence to support the claim that it is best practice? As part of the investigation it is im portant to examine the performance difference between the new practice and the normal ap proach. If the new practice outperforms the cur rent approach, then this helps to support the case for the adoption of the new approach. Looking at evidence from more than one source can help to validate the superiority of the prac tice. For example, if several organizations are using it, then it could be a practice worth adopting. It may also be a good idea to consider the opinions of independent experts. For example, the views of industry experts and aca demics about the proposed practice can be taken into consideration. Of course, some best prac tices may not require validation since they have been in use by companies for some time and have become tried and tested over the years.

### The Transfer of Best Practices

While there may be some evidence (usually case study based) to support the case of specific prac tices improving performance, a few writers have drawn attention to the fact that there are rela tively few large scale studies that empirically link practices with performance (Davies and Kochhar, 2002). They point to a need for more research into the relationships between oper ational practices and performance. For instance, the transfer of practice from one organization is based upon a number of assumptions (Wareham and Gerrits, 1999), each of which needs to be critically appraised.

- *Homogeneity of the organization.* The intro duction of a best practice from one organiza tion to another assumes a certain degree of homogeneity. The two organizations should resemble each other, in some measure, in order to allow the transfer to take place. In particular, the process, the technology, or the environment may need to be similar to a certain extent.
- *Universal yardstick.* Another basic assump tion of best practice is the existence of some kind of absolute measurement against which the superior performance of a practice can be measured (and then compared to other prac tices to determine which is best). However, there is some question whether such a uni versal yardstick can ever exist.
- *Transferability.* It is normally the case that some adjustment to the practice will be re quired to comply with the characteristics of the receiving organization. Only on rare oc casions can the best practice be transplanted into another organization with a minimal amount of modification. In most instances, the best practice has to be adapted before it can be implanted.

The adoption of a best practice may improve performance in one area but result in deterior ation in another (Davies and Kochhar, 2002). Adopters need to be aware of the impact on performance of the implementation of a best practice. Which areas of performance does it impact, are there any areas where performance may in fact decline?

There are several specific barriers to the suc cessful transfer of best practice (Szulanski, 1995; O'Dell and Grayson, 1998; Wareham and Ger rits, 1999). One of the major barriers to transfer is the absorptive capacity of the recipient. A manager may not have the resources (time and/or money) or enough practical detail to implement it. A further barrier to transfer is the lack of a relationship between the source of the practice and the recipient. If a relationship does not exist, then the source may be hesitant in helping the recipient; the recipient may not make the effort to listen and learn from the source. Moreover, a lot of important information that managers and workers need to implement a practice cannot be codified or written down. It has to be demonstrated to the recipients of the practice. If the practice contains a lot of tacit knowledge (know how), then it is likely that the transfer will not be simple. It is important that the organization recognizes the value of trying to capture tacit knowledge – the know how, judgment, and intuition that constitute the non codified knowledge that may make the dif ference between success and failure in the pro cess of transfer. The transfer of employees who know about the practice and/or insuring that personnel have been extensively trained should improve the chances of a successful transfer. Given the barriers that exist to the transfer of best practices, it is important that organizations take the time and plan the transfer of practices.

See also *benchmarking; breakthrough improve ment; business excellence model; continuous improvement; importance–performance matrix; Six Sigma*

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## bill of materials

*Peter Burcher*

The bill of materials (BOM) is a file or set of files which contains the "recipe" for each finished product assembly in a material requirements planning (MRP) system. It consists of informa tion regarding which materials, components, and subassemblies go together to make up each fin ished product, held on what is often known as a product structure file. Associated data about each item, such as part number, description, unit of measure, and lead time for manufacturing or pro curement, are held on a part or item master file.

For each finished product, a bill of materials is originally created from design and process planning information. The designs might be developed internally or be supplied by the customer. They will initially be in the form of drawings and material lists. The process plan ning information may be in the form of assembly charts. Together with information on the rele vant lead times, these form the basis of the inputs to the BOM.

While most MRP systems can cope with part numbers allocated at random, it is necessary for all items within the organization to be given a unique part number. Clearly, the information on the BOM needs to be accurate, since inaccur acies can lead to incorrect items or incorrect quantities of items being ordered. This accuracy needs to be audited. However, in many operat ing environments, there are continual changes to the BOM in the form of product modifications. These modifications may originate from many sources, such as safety legislation, production process changes, improvements for marketing purposes, or value analysis exercises. The con trol of the implementation of modifications can be a time consuming task, especially since factors such as the depletion of unmodified stocks and the timing of combined modifications have also to be considered.

There is an accepted numbering system for BOM levels which allocates level 0 to the fin ished product and increases the level number as the raw material stage is approached. Items that appear at several levels in a BOM, e.g., in the final assembly as well as in subassemblies, are usually assigned the lowest level code at which the item occurs. This insures that when MRP processing proceeds from one level code down to the next, all gross requirements for the item are accumulated before continuing any further (*see* NETTING PROCESS IN MRP).

The number of levels of assembly breakdown is determined by the complexity of the product; however, some BOMs are unnecessarily compli cated by including too many subassembly stages, and many companies have made determined efforts to flatten their BOM structures.

Bills of materials for hypothetical products are sometimes created to help in the forecasting and master production schedule of products which could have an extremely wide variety of saleable end items. These are referred to as planning BOMs, and may take the form of modular BOMs or BOMs which separate out common items from optional items and features. For example, in car production, there may be thou sands of items common to each model; there may also be optional items such as air conditioning assemblies and features such as an automatic gearbox or a manual gearbox. If forecast ratios of the take up of these optional and feature sub assemblies can be determined, then a planning BOM can be created using these ratios as the "quantity per" parent hypothetical finished product. It is these planning BOMs that are then used for master production scheduling in this environment.

See also *family bill; kit bill; manufacturing re sources planning; material requirements planning; modular bill; super bill*

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## blueprinting

*Robert Johnston*

The term "blueprinting" refers to the documen tation of a service process: it is a means of evaluating, developing, and designing service processes. Blueprinting is not just confined to documenting customer processes but is intended to help design the interrelationships between material, information, and customer flows. There are several ways of documenting service processes, e.g., decision charts, process charts, customer processing framework, and blueprints (as described by Shostack, 1984). All of these methods essentially involve the identification of the different stages in a service process. They can be made more sophisticated by the addition of lines of visibility, lines of interaction, time frames, the identification of control points and mechanisms, and the location of responsibility for each stage of the process. The benefit of blueprinting in the design of service processes is that the process can be checked for complete ness and over complexity, to see whether it meets the strategic intentions of an organization and to help identify and remove potential fail points as well as to help identify potential improvements.

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## bottlenecks

*Colin Armistead*

Bottlenecks are the parts of an operation or pro cess that are the constraints on its capacity. Bottlenecks are an important issue in operations management because most operations attempt to maximize the output from a given set of resources, and maximizing output means minimizing capacity "leakage" and improving throughput efficiency, which depends on under standing bottlenecks.

The question that arises for operations man agers is the extent to which bottlenecks are fixed or moveable as the variety or mix of products or services alters. There are two main approaches to managing bottlenecks. The first is to try to eliminate the bottleneck, recognizing that this will create another bottleneck step in the pro cess. The alternative is to manage the bottleneck so that it is never unnecessarily idle by insuring that resources needed at the bottleneck are always available (perhaps by using buffers), and insuring that changeovers cause minimum loss of capacity. Managing a bottleneck means insur ing that its utilization is as high as possible. If the bottleneck is fairly stable, there is also the need to make sure subsequent stages in the process after the bottleneck do not become bottlenecks themselves, otherwise the important work at the main bottleneck may be wasted. The theory of constraints gives simple rules for managing bottlenecks when they are reasonably stable in a process (*see* OPTIMIZED PRODUCTION TECH NOLOGY).

The rules are:

1. Balance flow not capacity.
2. The level of utilization of a non bottleneck resource is not determined by its own poten tial (capacity) but by some other constraint (i.e., bottleneck) in the system.
3. Making a resource work (activation) and util ization of the resource are not the same.
4. An hour lost at a bottleneck is an hour lost for the total system.
5. An hour saved at a non bottleneck is a mirage, unless resources can usefully be employed elsewhere.
6. Bottlenecks govern both throughput and buffer stocks.

7 The size of the batch we move between stages may be less than the process batch size at one stage. This allows us to prevent bottleneck stages running short of material.
8 The process batch should be variable, not fixed, allowing us to influence lead time and throughput efficiency.
9 Schedules should be established by looking at all constraints simultaneously. Lead times are a result of the schedule.

See also *balancing loss; business process redesign; layout; line balancing; product layout*

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## bow-tie and diamond perspectives

*Pietro Romano*

Cooper et al. (1997) reported an analogy attributed to the late Sam Walton according to which firms can choose between the bow tie and the diamond approaches to interfirm relationships. The bow tie is made up of two triangles meeting at a point. The traditional, often adversarial, relationship uses a bow tie approach where the primary or only interaction between firms is the buyer of one firm and the seller of the other firm. All information is transmitted through these two filters. The diamond occurs when the triangles are rotated so that two sides are together. In this case all the functions can talk with one another across firms. The salesperson and the buyer are at the farthest points and may essentially disappear in some instances. Both expected and serendipitous efficiencies can occur from these closer, partnership style relationships across other functions.

See also *purchasing; strategic account management; supply chain management*

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## breakthrough improvement

*Nigel Slack*

The breakthrough approach to improvement (or innovation based improvement) sees the main vehicle of improvement as major and dramatic changes in the way an operation works. The impact of these improvements is relatively sudden, abrupt, and represents a step change in practice (and hopefully performance). Such improvements often call for high investment of capital, often disrupting the ongoing workings of the operation and frequently involving changes in the product/service or PROCESS TECHNOLOGY. The archetypal breakthrough improvement method is sometimes cited as that of business process reengineering with its emphasis on radical change. The breakthrough improvement approach is often contrasted with that of CONTINUOUS IMPROVEMENT, but in reality may be combined with it.

See also *business excellence model; business process redesign; sandcone model of improvement*

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## build-to-order

*Matthias Holweg*

Build to order (synonym: make to order) represents the classic "pull" production strategy whereby production is initiated by an actual customer order, as opposed to a "push" strategy whereby production is driven by a long term forecast, and products are sold from existing finished goods inventory (FGI) in the market place. Essentially, the goal of any manufacturing system is to produce exactly what customers want, when they want it. Building exactly what the customer wants in short lead times not only provides high customer service levels and significantly reduces inventory costs, but also can provide a crucial competitive advantage in the marketplace (Stalk and Hout, 1990). Some companies attempt to meet individual buyers' needs through a mass customization strategy, such as late configuration (Lampel and Mintzberg, 1993; Gilmore and Pine, 1997), but often manufacturers revert to manufacturing standard products, in bulk, according to long term forecasts in the hope that the supply will be in line with actual demand. The driver behind this strategy is the notion that forecast driven operations enable efficient production, as capacity can be kept stable even if demand drops temporarily (Raturi et al., 1990). Any industry that supplies customized high volume products – such as automobiles, furniture, and electronics, for example – will be tempted to rely on strategies that push finished goods into the market, because of the more predictable revenues that are crucial to offset production and development costs. In markets where product customization is explicitly demanded, however, forecast driven systems show clear strategic disadvantages.

### The Vicious Cycle of Making to Forecast

The basis for push strategies is a demand forecast, which due to the very nature of forecasting is bound to be wrong (*see* FORECASTING PROCESS) and subsequently often results in over or understocking, or quite simply having the wrong products in stock. Either way, service levels suffer, and cost goes up. As a result, companies are burdened with inventory holding costs and, if demand proves weaker than expected, frequently have to resort to selling their products using costly sales incentives, such as discounts. Furthermore, with increasing product variety offered in the market, the likelihood of finding a customer–product match decreases significantly, further increasing the need for these sales incentives. In particular in markets where high customization levels are required, this can lead to a vicious cycle (Holweg and Pil, 2001): as incentives are used to clear unwanted stock, or persuade customers to accept a poor customer–product match, the revenue per product sold decreases. To compensate for eroding profit margins, even more emphasis is put on pushing volume into the market, and in this way recovering the development and production cost.

Second, even when the customer asks for a custom built product, the delivery lead time is bound to increase the more the company uses push strategies, as the system was not created to support build to order (BTO), and thus customer and forecast orders will compete for production resources. As a result, order to delivery (OTD) lead times will increase, discouraging customers from ordering, and fostering sales from readily available products in stock. The more products a company sells from stock, however, the more disconnected it becomes from real customer demand and the less likely its sales forecasts will match real customer requirements. As the cycle perpetuates, the company finds itself building a larger and larger proportion of products to forecast, and the use of the more profitable build to order strategies becomes increasingly remote. In summary, the vicious circle of making to forecast has two elements: in the first, the company must rely on larger economies of scale to compensate for the use of push based selling. In the second, the company loses sight of real customer requirements be cause it is selling too many products from stock, and is unable to capture actual demand patterns in the market.

### Responsive System versus Efficient Factory

In sectors where products are customized to order, i.e., where non standard products are manufactured (e.g., automobiles), or standard components are assembled to customer order (e.g., electronics), or standard products are con figured to customer wishes (e.g., bicycles), making products to forecast has significant disadvantages.

Building products to order, rather than to forecast, can circumvent the problems inherent in the make to forecast scenario. The strategic focus in a build to order environment turns away from production efficiency and unit cost toward adopting a systemic, or holistic, view of the effectiveness of the whole supply chain system. Here production efficiency is still a con cern, but so are customer fulfillment and the responsiveness to customer demand. The key measure is maximizing revenue per unit, not minimizing manufacturing cost per unit. A build to order strategy aims to develop the cap ability for a company to react quickly to changes in demand, so the system can operate with the costly practices of holding inventory costs and using sales incentives.

On the downside, build to order makes the manufacturer susceptible to demand swings in the market. Ultimately, any production system will fail if demand subsides, yet in forecast driven manufacturing systems, a buffer of finished goods can insure that the capacity is utilized even during seasonal troughs (cf. pro duction smoothing). A build to order system hence needs to create flexibility on multiple di mensions to achieve such systemic responsive ness, including for example, the alteration of information systems or the alignment of product designs. In order to implement a successful build to order strategy, one needs to have flexi bility on three dimensions: process, product, and volume flexibility. It is the synergy between flexibility on all three levels that creates true system responsiveness to customer demand and enables the sustainable adaptation of a build to order strategy (for a comprehensive discussion see Holweg and Pil, 2004).

### Process Flexibility

Process flexibility essentially means to connect the customer to the value chain, or make the customer order the pacemaker of the entire supply chain. With regards to SUPPLY CHAIN DYNAMICS, making to order (as opposed to forecast) has a dampening impact on the so called “Forrester” or “bullwhip” effect, which is much less likely to occur in demand driven supply chain settings (Forrester, 1958; Lee, Padmanabhan, and Whang, 1997). The bullwhip effect is an artificial demand distortion caused by forecasting, batching, and multiple decision points and worsened by inventory and long lead times in the system. Process flexibility centers on the speed at which the company can make decisions, alter schedules, or amend existing orders to customer needs. It determines, for example, how quickly the company can translate information at the customer interface into organizational decisions and operating man dates. Because it cuts across all parts of the value chain, process flexibility cannot be achieved without involving suppliers and distributors. Main strategies here include the close integra tion of supplier and logistics service providers, and the use of Internet based intercompany communication, in order to achieve seamless and synchronized deliveries.

### Product Flexibility

Product flexibility refers to the company’s abil ity to adapt a product to the customer’s specifi cation, as well as the company’s ability to delay or reduce the degree to which it must tailor the product. This level of flexibility provides a crit ical interface between marketing (i.e., the variety offered to the customer), design (i.e., how the variety is integrated into the product), and manufacturing (i.e., how complex the product is in manufacturing). Essentially it is the product design that determines how the *external* variety in the marketplace translates into the *internal* variety in the manufacturing process. Strategies related to product flexibility include the mass customization continuum, modularity, post ponement, and late configuration. The general notion in a build to order system is to bring customization closer to the customer in order to reduce both lead times and the adverse impact of variety on the manufacturing operations. Managing product variety through common part ratios and the introduction of mutable support structures are common approaches, for example. Mutability implies that the same support structures can be utilized to provide the level of uniqueness and customization required by each customer. Mutable support structures, such as product platforms for example, enable greater variety while reducing internal complexity.

Volume Flexibility

Volume flexibility is a company's ability to re spond to overall changes in demand by altering production volume accordingly. The ability to cope with short term variability, seasonality, and changing demand over the life cycle of the prod uct is critical to the success and sustainability of a build to order system. In particular, reducing the dependency on full capacity utilization and the ability to reduce and increase capacity with out large cost penalties require critical assess ment. The impact on capacity utilization is a major concern many companies have in imple menting build to order. When existing capacity is not used, and especially when demand falls below break even levels, the temptation will rise to revert to forecast driven production. How ever, any production system will fail if demand drops, regardless of whether it stockpiles prod ucts or builds to order. Thus, being able to manage short term variability in demand is key. Achieving volume flexibility has two key elements: first, focusing on increasing respon siveness at factory level, and second, actively managing the demand flow.

One way to achieve responsiveness at factory level is to reduce the financial need to keep the factory going at the same rate all year through the introduction of flexible work hour arrange ments (such as "hour banks," sometimes also referred to as "annual hours"), which alleviate the cost penalty of using overtime and temporary workers to cope with demand swings. Further more, a diversification of production plants means that large, efficient, but less flexible plants could provide for the stable base demand, and smaller, less efficient, but flexible plants could cater to low volume demand and provide additional capacity if demand changes (Mini mills in the steel industry are a classic example; see also Pil and Holweg, 2003). It is further important to note that the volume rigidities that exist at the factory level also exist at supplier organizations, so volume flexibility at the manu facturing plant level alone is of little impact if the supply chain does not match this capability.

In terms of demand management, the concept of revenue management, i.e., the use of differen tiated pricing to manage demand with the ob jective of maximizing revenue, is common in service sectors, yet an often missed opportunity in manufacturing supply chains. Relating price to the speed of delivery means that price sensitive customer segments can be used to smooth demand: products ordered well in ad vance create long term visibility and lower the cost of making the product, hence can be offered at a lower price. The demand visibility created helps to manage and smooth capacity utilization in both product assembly and the wider supply chain. This cost saving is partially passed on to the customer to encourage the most beneficial flow of demand for the manufacturer. Long term visible orders can also help buffer the short OTD lead times needed for lead time sensitive customer segments, which generally yield high margins (e.g., luxury and fashion products).

Related Concepts

In a wider sense, build to order fits into the discussion centered around mass customization strategies. Many operations concepts have been proposed on how to achieve mass produced, customized products, yet most fail to go beyond the product or process dimensions (e.g., late configuration, which only touches upon the product dimension). The key to a successful build to order strategy, however, is to strive for flexibility in all three organizational dimen sions – product, process, and volume – in order to attain the critical responsiveness at system level, and not simply create further islands of excellence in the supply chain.

A close sibling of build to order is the *assem ble to order* concept, whereby the end product is assembled to customer order based on standard components that are kept in inventory on site. This concept works well in low complexity en vironments with modular products, which allow for "plug and play" configuration. A strategic disadvantage here is the component inventory that has to be held close to the assembly oper ation, which also represents a decoupling point in the system (a decoupling refers to the point where "push" and "pull" elements in a supply chain meet). Assemble to order is best known through the case of Dell Computers, which has applied the concept very successfully in its "direct" business model. Misleadingly, Dell sometimes refers to its approach as *build to order*, although technically speaking it is an *assemble to order* system.

See also *flexibility; P:D ratios*

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## business excellence model

*Rodney McAdam*

The European Quality Award (EQA) model was launched in 1992. Since then the title of the model has undergone several permutations, al though it is mainly recognized as the business excellence model (BEM). Those involved in the formation of the model included leading total quality management (TQM) practitioners and academics from organizations and universities in the UK and Europe. Since its inception the model has remained largely unchanged. In April 1999 minor modifications were introduced to improve and clarify wording. The model is used in the European Quality Award, while the Malcolm Baldrige model is the equivalent in the US. Other models used in National Quality awards are usually based on these models. The model is shown in figure 1 (EFQM, 2003).

The model is supposed to represent the process of TQM and the aspiration toward business excellence in organizations from all sectors. It is formed on the underlying assump tion of cause and effect. The nine boxes are the nine criteria, which are split into five enabling (or causal) criteria and four results (or effect) criteria. The backward facing arrow in figure 1 indicates that learning cycles, fostering innov ation and learning, are seen as being present in the model.

Each enabler criterion is subdivided into sub criterion parts, which can be assessed for a given organization. The process of self assessment is used to evaluate organizations in relation to the model. Typically, for a large organization, a trained internal self assessment team will assess the organization down to a subcriterion part level. For each subcriterion part, strengths, weaknesses, areas for improvement, and a score will be identified.

The results criteria are mainly divided into perceptive and non perceptive data with a focus on the excellence and scope of the results. Once again, the self assessment team identifies strengths, weaknesses, areas for improvement, and a score, this time at criterion level.

The assessment process is referred to as RADAR logic, an acronym for results, approach, deployment, assessment, and review. Assess ment and review are used when assessing enabler criteria and the results element is used when assessing results criteria.

The process of self assessment can be carried out in a number of ways. The generic approach is shown in figure 2. Two typical approaches are the simulated award process and the management workshop approach. In the simulated award approach, the organization or the department being assessed constructs a written document describing how the organization addresses the areas outlined in the model down to subcriterion part level. This document is then assessed

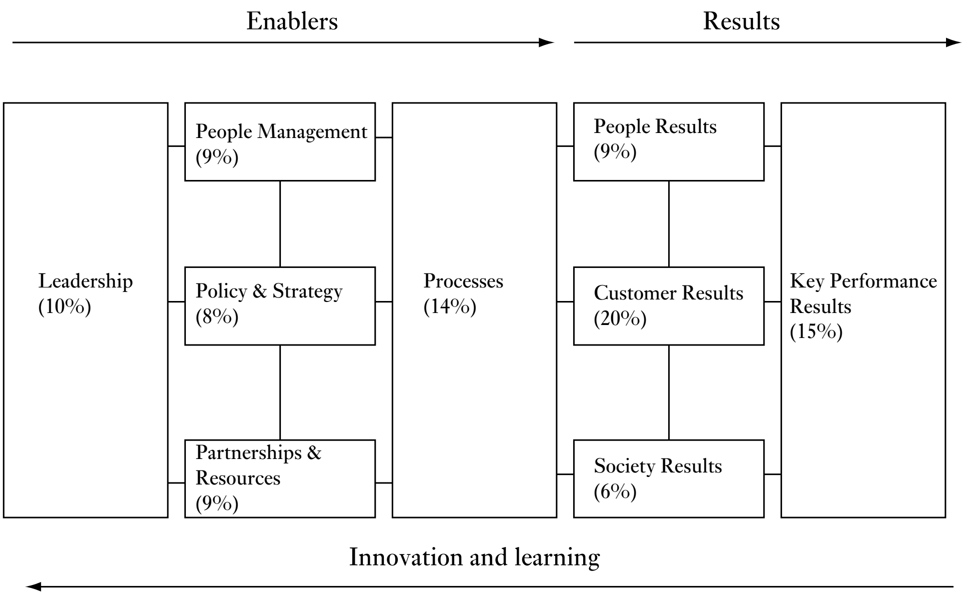


**Figure 1** The business excellence model

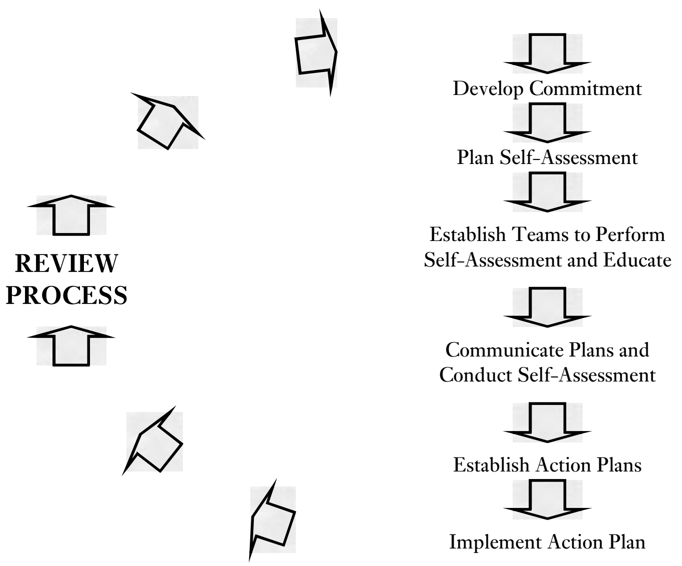


**Figure 2** The process of self-assessment

by the internal self assessment team. This method is rigorous but takes considerable time and resources. The management workshop ap proach involves a group of managers reaching consensus on an electronically displayed pro forma of the model and its subcriterion parts. This approach relies on the Pareto principle of identifying 80 percent of the vital points while at the same time using little time and resources (*see* PARETO ANALYSIS). The model is described as follows.

Leadership

Excellent leaders develop and facilitate the achievement of the mission and vision. They develop organizational values and systems re quired for sustainable success and implement these via their actions and behaviors. During periods of change they retain a constancy of purpose. Where required, such leaders are able to change the direction of the organization and inspire others to follow.

Leadership covers the following five criterion parts that should be addressed.

1(a) Leaders develop the mission, vision, values, and ethics and are role models of a culture of excellence.
1(b) Leaders are personally involved in insur ing the organization's management system is developed, implemented, and continuously improved.
1(c) Leaders interact with customers, part ners, and representatives of society.
1(d) Leaders reinforce a culture of excellence with the organization's people.
1(e) Leaders identify and champion organiza tional change.

Policy and Strategy

This criterion covers all aspects of the develop ment and communication of business strategy and business plans. The subcriteria are as follows:

2(a) Policy and strategy are based on the pre sent and future needs and expectations of stakeholders.
2(b) Policy and strategy are based on informa tion from performance measurement, re search, learning, and external related activities.
2(c) Policy and strategy are developed, reviewed, and updated.
2(d) Policy and strategy are communicated and deployed through a framework of key processes.

People Management

Excellent organizations manage, develop, and release the full potential of their people at an individual, team based, and organizational level. They promote fairness and equality and involve and empower their people. They care for, communicate, reward, and recognize, in a way that motivates staff and builds commitment to using their skills and knowledge for the bene fit of the organization.

People Management covers the following five criterion parts that should be addressed.

3(a) People resources are planned, managed, and improved.
3(b) People's knowledge and competencies are identified, developed, and sustained.
3(c) People are involved and empowered.
3(d) People and the organization have a dia logue.
3(e) People are rewarded, recognized, and cared for.

Partnerships and Resources

Excellent organizations plan and manage exter nal partnerships, suppliers, and internal re sources in order to support policy and strategy and the effective operation of processes. During planning and whilst managing partnerships and resources, they balance the current and future needs of the organization, the community, and the environment.

Partnerships and Resources cover the following five criterion parts that should be ad dressed.

4(a) External partnerships are managed.
4(b) Finances are managed.
4(c) Buildings, equipment, and materials are managed.
4(d) Technology is managed.
4(e) Information and knowledge are managed.

### Processes

Excellent organizations design, manage, and im prove processes in order to fully satisfy, and generate increasing value for, customers and other stakeholders.

Processes cover the following five criterion parts that should be addressed.

- 5(a) Processes are systematically designed and managed.
- 5(b) Processes are improved, as needed, using innovation in order to fully satisfy and generate increasing value for customers and other stakeholders.
- 5(c) Products and services are designed and developed based on customer needs and expectations.
- 5(d) Products and services are produced, de livered, and serviced.
- 5(e) Customer relationships are managed and enhanced.

### Customer Satisfaction

Excellent organizations comprehensively meas ure and achieve outstanding results with respect to their customers.

Customer Results cover the following two criterion parts that should be addressed.

- 6(a) Perception measures.
- 6(b) Performance indicators.

### People Satisfaction

Excellent organizations comprehensively meas ure and achieve outstanding results with respect to their people.

People Results cover the following two criter ion parts that should be addressed.

- 7(a) Perception measures.
- 7(b) Performance indicators.

### Society Results

Excellent organizations comprehensively meas ure and achieve outstanding results with respect to society.

Society Results cover the following two cri terion parts that should be addressed.

- 8(a) Perception measures.
- 8(b) Performance indicators.

### Key Performance Results

The measures are key results defined by the organization and agreed in their policy and strategies. Key Performance Results cover the following two criterion parts that should be ad dressed. Depending on the purpose and object ives of the organization, some of the measures contained in the guidance for key perfor mance outcomes may be applicable to key performance indicators, and vice versa.

- 9(a) Key performance outcomes.
- 9(b) Key performance indicators.

### Calculation of Total Points

To calculate the total points scored in a self assessment, the scores of each criterion out of 100 are multiplied by their respective weighting factor and the total obtained from the summa tion of all nine criteria. The criterion weightings have remained constant since the formation of the model and were arrived at by averaging the weightings suggested by each participating organization.

Although the BEM was formed primarily on the basis of large private sector organizations, there have been attempts to adapt the model for use in the public sector and for small organ izations. In the case of the public sector, the wording of the model has been adapted to reflect public sector language and limitations in regard to strategy and finance. In small organizations the number of criterion parts have been con densed in an attempt to make the process less bureaucratic.

### Critique of the BEM

The development of TQM in the latter part of the 1980s can be attributed to a number of reasons, not least the continued criticism of ISO 9000 for failing to deliver continuous improve ment. However, ISO 9000 was measurable and achievable while TQM remained somewhat ill defined. Thus, there was a need for a model or framework within which TQM could be defined and measured. In response to this need, the BEM was developed as being based on TQM principles and as being a measuring framework for TQM. Therefore, organizations applying TQM could measure their progress. Moreover, the scoring process enables TQM based BENCHMARKING between organizations or parts of organizations which are using the BEM. The danger in this approach is that benchmarking scores can be misleading and a more fundamental comparison of criterion part strengths and weaknesses is needed.

The European BEM (similar to the Baldrige model) is now in widespread use in many organizations. Various approaches to applying the model, emphasizing its advantages in the area of TQM, are well documented in the literature. These advantages include improved approaches, measurement, and benchmarking.

The key premise of the BEM is that it represents TQM within an organization. One way of critiquing this claim is to compare the model against each of the principles of TQM. Over the past ten years there has been a proliferation of TQM frameworks in the literature. Jamal (1998) provides a useful synthesis of the literature based on the work of Hackman and Wageman (1995) and Spencer (1994). The resultant key principles of TQM are:

1 TQM is strategically linked to the business goals.
2 Customer understanding and satisfaction are vital.
3 Employee participation and understanding at all levels are required.
4 There is a need for management commitment and consistency of purpose.
5 The organization is perceived as a series of processes which incorporate customer–supplier relationships.

This TQM framework is used to critique the BEM's claim to represent TQM in an organization.

1 *TQM is strategically linked to business goals.* The EQA model claims to support this TQM principle in a number of ways. First, the nine criteria represent a business in its totality; second, policy and strategy is a key criterion; and third, the result criteria give some idea of successful strategy. However, the EQA model does not formulate strategy, nor does it properly evaluate strategy, it evaluates the process of forming strategy. The danger in this limited involvement in the strategic process is that TQM could be seen as simply a strategic audit tool rather than as intrinsically linked with strategy.
2 *Customer understanding and satisfaction are vital.* In this area of TQM the EQA model is seen as making a significant contribution. Customer satisfaction is a key result criterion and links must be shown back to enabling criteria. Customer satisfaction ratings can also be benchmarked across other organizations. One cause for concern is the lack of a predictive element that would help identify new customers and markets, reflecting the lack of strategic integration referred to already.
3 *Employee understanding and participation are required at all levels.* The EQA model has both people management and people satisfaction enabler and result criteria, respectively. This enables approaches to people involvement to be evaluated and benchmarked. However, there are a number of problems in this area. First, the model is an audit tool of what is already happening, it does not indicate best or preferred practice in an organizational context. Second, TQM is often translated through the workforce by simple, easily understood approaches. The EQA model remains rather complicated and bureaucratic in this respect.
4 *There is a need for management commitment and consistency of purpose.* The leadership criterion is a key enabler within the model. It is based on a coach/mentor style of leadership that advocates a role modeling approach. This style of leadership is very supportive of the TQM framework. Perhaps this definition of leadership is not appropriate in all business circumstances and emphasizes the limitations of defining all organizational settings within a rigid model.
5 *The organization is perceived as a series of processes.* Central to the EQA model is the business process criterion. This criterion defines a series of steps for systematic management and improvement of business

processes. However, the model does not show how business processes can be identi fied or improved – it remains as a detached audit tool. Also, it may not be appropriate for organizations to be completely process based; there may be a partial process func tional structure. The model takes no account of this situation.

In summary, the EQA model has merit as a business audit approach but should not be viewed as synonymous with TQM; rather, it is a technique within TQM. If the model is taken as synonymous with TQM, then its limitations as described above could lead to unwarranted questioning of the broad field of TQM.

The use of the term excellence in the BEM also helps in critiquing the BEM in relation to TQM. Organizational excellence (OE) is cur rently a key stage on the TQM journey and is composed of contributions from various man agement discourses. TQM terminology associ ated with quality as a continuous journey is used by Ruchala (1995): "a continuous quest . . . [from] employee improvement to achieving excellence." Periera (1994) describes stages in this journey as self assessment, customer ser vice, and commitment to excellence. Castle (1996) describes the overall TQM journey as stages of a learning and culture change process. Dale and Lascelles (1997) divide the TQM jour ney into several key stages, dependent on organ izational growth and development, culminating in "world class" status. Organizations who refer to their TQM progress in regard to a particular stage frequently state that their organization has "started the journey to business excellence," each key stage of this journey being character ized by the use of differing methodologies, all dependent on the same TQM theoretical framework.

It was not until 1982 when Peters and Water man published their text, *In Search of Excellence*, that the word became directly associated with levels of business performance (Castle, 1996). Their work outlined a number of key business areas as contributing to excellence: strategy and structure, systems, staff, skills, shared values, and so on. There have been a number of cri tiques of this work, e.g., Schmidt (1999) claims that of the 36 companies profiled, three are no longer listed on the stock exchange and only 12 outperformed the Standard and Poor's index over the last five years. Thus, until the 1980s at least, there is no record of business excellence as a key business influence. Schmidt (1999) raises the issue that many "excellent" organizations are excellent by reputation and not by objective critical analysis.

Throughout the 1980s and early 1990s the rapid development of the quality movement resulted in relatively little OE activity. The advent of the quality award models in the early 1990s, e.g., the European Quality Award, the Baldrige Award, gave an impetus to OE. Some have changed their names to excellence awards, e.g., Business Excellence Award, Australian Ex cellence Award. Organizations scoring over or around 600 points on these models are deemed to have reached a state of excellence. However, the failure of many of these organizations to maintain their positions shows that a defined state of OE does little to bolster business confi dence beyond the hype of quality or excellence awards.

See also *breakthrough improvement; continuous improvement; quality; sandcone model of improve ment; self assessment models and quality awards; total quality management*

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## business process redesign

*Alan Harrison*

Business process redesign (BPR) was conceived in an MIT research project during the late 1980s and popularized by an article by Michael Hammer (1990). The title of his article, "Reengineering work: Don't automate, obliterate," claimed that something new and radical was being launched into the business world. Of particular significance is the cross functional view that BPR takes of business processes, the radical nature of the changes proposed, and the enabling role of information technology in facilitating those changes.

The term "business process" refers to sequences of related process elements which produce business benefits. Key aspects of this definition are that business processes are large scale, concerned with "the business," as distinct from small scale, localized processes. They tend to span several business functions and they are composite, i.e., they can be conceived as comprising groupings of process elements which in turn can be broken down into activities and tasks.

BPR can be defined as the radical reshaping of business processes, taking full advantage of modern developments in information technology (IT). Key aspects of this definition are that BPR is first of all radical. Hammer (1990) refers to the need to start with a blank sheet of paper and to reinvent the enterprise. Second, it is concerned with reshaping. Existing business processes are transformed into new, greatly simplified processes that are much faster, more flexible, and better quality. Third, it is dependent on improvements in IT. A key aspect of BPR as a concept is making use of the opportunities provided by modern developments in IT. However, IT is viewed as an enabler of BPR rather than a driver.

The BPR approach aims to discard non value adding (wasteful) processes in favor of those adding value, as does JUST IN TIME. It aims to simplify business processes and thereby to reduce cycle times, e.g., where several possible tasks are combined into one. Tasks are compressed so that an individual carries out what several did before. Workers make decisions, so that decision making becomes part of the process and management a broadly shared activity. Process elements are performed in a natural order to break the rigidity of the "straight line sequence." There are many versions of each process so as to provide flexibility to meet different market needs. Work is performed where it makes most sense and organizational boundaries are loosened. Checks and controls are reduced to those that make economic sense. Reconciliation is minimized by cutting back on the number of external contact points of a given process. A "case manager" provides a single point of contact so that one person is responsible for the overall business process and acts as a single contact point for the customer.

While some of these recurring themes may contradict one another, the challenge of redesign is to maximize their potential in a given situation.

### Origins of BPR

The concept of radical improvement is not new. For example, Hayes and Wheelwright (1984) contrast the "hare" and "tortoise" approach to change in manufacturing. At around the same time, MIT set up a five year research program called "Management in the 1990s" or MIT90s for short. Its objectives were to develop a better understanding of the managerial issues of the 1990s and how to deal most effectively with them, particularly as these issues revolve around anticipated advances in IT.

A key aspect of the research was the recognition of IT as a strategic resource which not only provides opportunities to improve complex business processes but which can also help to extend the scope of the organization itself. MIT90s research envisaged five levels of application of IT to support different degrees of business transformation:

1 *Localized exploitation*: IT implementation is limited to a division or department, such as an order entry system.
2 *Internal integration*: IT implementation is carried out on an integrated platform across the organization.
3 *Business process redesign*: IT implementation makes new business processes possible within the organization.
4 *Business network redesign*: IT implementation is aimed at redesigning the way in which exchanges take place between members of a business network. The term "network" ap plies not just to electronic links, but encom passes all business dealings between members.
5 *Business scope redefinition*: The "scope" of a business refers to the range and breadth of its activities, covering the definition of its boundaries with suppliers and customers and the criteria it uses to allocate its resources.

Levels 1 and 2 are viewed as evolutionary in that IT implementation does not require redesign of business processes. Levels 3, 4, and 5 are viewed as revolutionary because IT implementation demands that business processes are redesigned.

## BPR and Risk

The conceptualization of revolutionary change contrasts with the bottom up, wide scale in volvement that is the hallmark of CONTINUOUS IMPROVEMENT. A BPR project may be a one off, taking perhaps several years to complete and involving detailed long term planning. This raises the possibility that, because of the long development time, a large scale improvement promised through BPR may not be available when it is most needed. Further, the change may prove difficult to manage for an organiza tion where change is not already part of the culture. Because BPR addresses broad, cross functional business processes rather than individual activities and tasks, it typically is im plemented top down by teams of senior person nel (process improvement teams) with top team (steering committee) support. Participation by people in the front line of the organization may not be wholehearted, especially if jobs are threatened.

The risks of mismanaging change using the BPR route are therefore much greater than with the continuous improvement route because of the very nature of the scope of the changes proposed. Some 50 to 70 percent of BPR pro jects are described as failing to achieve the results intended (Hammer and Champy, 1993). A misjudgment in the implementation of con tinuous improvement, on the other hand, may result only in one step not being fulfilled. In some circumstances, however, there is little choice but radical change.

## Implementing BPR

The procedure for implementing BPR has often been packaged into a series of steps or phases. Those described by Harrington (1991) are typical.

- *Phase 1: Organize for improvement by building leadership, understanding, and commitment*. A steering committee (executive improvement team) is formed to oversee the improvement effort. A redesign "champion" is appointed to enable and coordinate action, and a pro cess improvement team(s) formed to tackle business processes. The purpose and organ ization of BPR is communicated to the whole workforce.
- *Phase 2: Understanding the current business process*. The team develops a high level understanding of how inputs are trans formed into outputs, the effectiveness of meeting customer expectations, and the effi ciency with which resources are used. A key tool is flowcharting, which graphically docu ments the activities and process elements that make up the business process.
- *Phase 3: Redesigning business processes to im prove flow, effectiveness, and efficiency*. The improvement team reinvents business pro cesses by envisioning the perfect business, aiming to simplify and reduce current pro cesses accordingly. The role of IT here is as an enabler to achieve the redesigned process.
- *Phase 4: Developing process measurements for feedback and action*. Key measures are related to the efficiency, effectiveness, and adapt ability of a process.
- *Phase 5: Continuously improve the process*. This starts with process qualification (defining and

verifying process capability), and continues with benchmarking (for goal setting and pro cess development). Issues from this phase are fed back to phases 2 and 3.

See also *balancing loss; bottlenecks; breakthrough improvement; design; layout; line balancing; ser vice design*

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# C

**capacity management**

*Nigel Slack*

The most common use of the word "capacity" is in a physical sense, e.g., as applied to the fixed volume of a container, or the space in a building. This meaning is also used in operations management. However, although these capacity measures describe the scale of operations, they do not necessarily reflect their processing capacities. This needs the addition of a time dimension appropriate to the use of the assets. Thus the definition of the capacity of an operation is the maximum level of value added activity over a period of time that the process can achieve under normal operating conditions.

## The Time Scale of Capacity Management

Capacity management is commonly viewed on three time scales: long term, medium term, and short term. This may be a somewhat misleading categorization because the boundaries between different time scales vary considerably for different types of operation. What may be regarded as medium term capacity management in one operation could be seen as short term in another. Nevertheless, with any industry, three categories are reasonably widely accepted.

At its most long term (and therefore strategic), capacity management is concerned with introducing (or deleting) major increments of physical capacity. This is termed CAPACITY STRATEGY and determines the physical capacity limits of the operation's processing capability. Typical decisions here relate to plant size, technology, and location.

Within the constraints of long term capacity, operations managers must decide how to adjust the capacity of the operation in the medium term. This usually involves an assessment of the demand forecasts over a period of 2 to 18 months ahead, during which time planned output can be varied, e.g., by changing the number of hours the equipment is used. This is often termed AGGREGATE CAPACITY MANAGEMENT because, although effective capacity is being managed with physical constraints (such as plant size), demand is still being treated in an aggregated manner.

Operations managers also have to make short term capacity adjustments, which enable them to flex output for a short period, either on a predicted basis or at short notice.

## Measuring Capacity

The main problem with measuring capacity is the intrinsic complexity of most operations' resources. Only when the operation is highly standardized and repetitive is capacity easy to define unambiguously. Here the output is the most appropriate measure of capacity because the output from the operation does not vary in its nature. For many operations, however, the definition of capacity is less obvious. Especially when a much wider range of outputs places varying demands on the process, output measures of capacity are less useful, so input measures may be used to define capacity.

All operations could use a mixture of both input or output measures. In practice though, most choose to use one or the other. In high volume, repetitive, low variety operations, output measures of capacity are often preferred, because of their predictable relationships to the required input resources. In complex operations producing a wide variety of outputs, each requiring different inputs, measures of capacity based on inputs are often considered to be most appropriate.

A further source of complexity is that capacity depends on activity mix. Because output depends on the mix of activities in which an operation is engaged and because most oper ations perform many different types of activities, output is difficult to predict.

### Design Capacity and Effective Capacity

The theoretical capacity of an operation (design capacity) cannot always be achieved in practice. Processes will need to be stopped while they are changed over, and for maintenance, and sched uling might also result in lost time. The actual capacity that remains, after such losses are ac counted for, is called the effective capacity of operation. Other factors such as quality prob lems, machine breakdowns, absenteeism, and other avoidable problems will also reduce output. Thus the actual output of a process may be lower than the effective capacity. The ratio of the output actually achieved by an oper ation to design capacity and effective capacity are called, respectively, the utilization and the effi ciency of the plant.

$$\text{Utilization} = \frac{\text{actual output}}{\text{design capacity}}$$

$$\text{Efficiency} = \frac{\text{actual output}}{\text{effective capacity}}$$

As a measure of performance, utilization has some drawbacks. Low utilization may result from many different causes, such as low demand, or because the plant is frequently breaking down, or running out of materials, or suffering labor unrest. Nor is seeking high util ization always desirable. Particularly in batch type operations, an emphasis on high utilization can result in the buildup of in process inventor ies (*see* JUST IN TIME).

### Queuing Theory in Capacity Management

Especially in service operations, queuing theory may be used to set capacity levels. Although service operations make forecasts of their expected average level of demand, they cannot usually predict exactly when each individual customer or order will arrive. A distribution which describes the probability of customers arriving might be known, but not each individual arrival. Furthermore, as well as the arrival of customers being uncertain, the time that each customer will need in the operation might also be uncertain. Customers arrive according to some probability distribution, wait to be processed (unless part of the operation is idle), when they have reached the front of the queue they are processed by one of several parallel "servers" (their processing time also being described by a probability distribution), after which they leave the operation. The capacity management issue here is how many parallel servers to have avail able for service at any point in time.

If the operation has too few servers (i.e., cap acity is set at too low a level), queues will build up to a level where customers become dissatis fied with the time they are having to wait, al though the utilization level of the servers will be high. If too many servers are in place (i.e., cap acity is set at too high a level), the time that customers can expect to wait will not be long but the utilization of the servers will be low. This is why the capacity management issue for this type of operation is often presented as a trade off between customer waiting time and system utilization.

Management scientists have developed for mulae that can predict the steady state behavior of different types of queuing system. Unfortu nately, these formulae can be extremely compli cated, especially for all but the most simple assumptions. In fact, computer programs are almost always now used to predict the behavior of queuing systems.

See also *overall equipment effectiveness; planning and control in operations; queuing analysis; service operations*

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## capacity strategy

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Capacity strategy is the term applied to an interconnected set of decisions which determine the long term capacity configuration of an organization. Typically, these decisions include the number and capacity of sites, their physical location, the allocation of tasks to individual sites, and the magnitude and timing of any change to total capacity in response to changes in long term demand.

In terms of capacity strategy decisions affecting a single existing site, three issues warrant particular attention. These are the absolute level of capacity of a site, the size of any incremental change in capacity, and the timing of the change.

### The Optimum Capacity Level

The amount of capacity to provide is a fundamental decision for operations managers. If more capacity is provided than is justified by demand, the resources that constitute the capacity will be underutilized. Conversely, if demand is greater than provided capacity, sales and therefore revenue will be lost. In this way the level of capacity chosen by an operation will directly affect its operating profitability. Beyond this, however, because the provision of capacity usually involves investment in resources, the decision also affects the level of the operation's asset base.

At activity levels below its capacity the average cost of producing each unit will increase because the fixed costs of the factory are being covered by fewer units produced. The unit cost of producing $x$ units is then given by the formula:

$$C_x = (\mathrm{FC}/x) + \mathrm{VC}$$

where $C_x$ is the unit cost of producing $x$ units, FC is the fixed costs of the operation, and VC is the variable cost of producing one item.

According to this formula the average cost of producing the units seems to reach its lowest point at maximum capacity; however, the actual average cost curve may not conform to this theoretical relationship. There may be cost penalties of operating the plant at levels close to or above its nominal capacity. Long periods of overtime may reduce productivity levels as well as costing more in extra payments to staff, operating plant for long periods with reduced maintenance time may increase the chances of breakdown, and so on. This usually means that average costs start to increase after a point that may be lower than the theoretical capacity of the plant.

A similar relationship occurs between the average cost curves for plants of increasing size. Figure 1 illustrates a series of average cost curves. At first, as the nominal capacity of the plants increases, the lowest cost points reduce for two reasons. First, the fixed costs of an operation do not increase proportionately as its capacity increases. Second, the capital costs of building the plant do not increase proportionately to its capacity. The reason for this is that whereas the capacity of many types of plant and equipment are related to their volume (a cubic function), the capital cost of the plant and equipment is related to its surface area (a square function). Generally, the cost ($C_y$) of providing capacity (in one increment) of size $y$ is given as follows:

$$C_y = K_y^k$$

where $K$ is a constant scale factor and $k$ is a factor which indicates the degree of the economies of scale for the technology (usually between 0.5 and 1.0).

These two influences, taken together, are often referred to as *economies of scale*. However, above a certain capacity, the lowest cost point may increase. This occurs because of *diseconomies of scale*, two of which are particularly important. First, transportation costs can be high for large operations because supplies may have to be brought from several suppliers to the single plant and all products shipped from there throughout its market. If the company has several smaller plants located closer to their relevant markets and suppliers, transportation costs could be lower. Second, complexity costs increase as capacity increases. Organizations

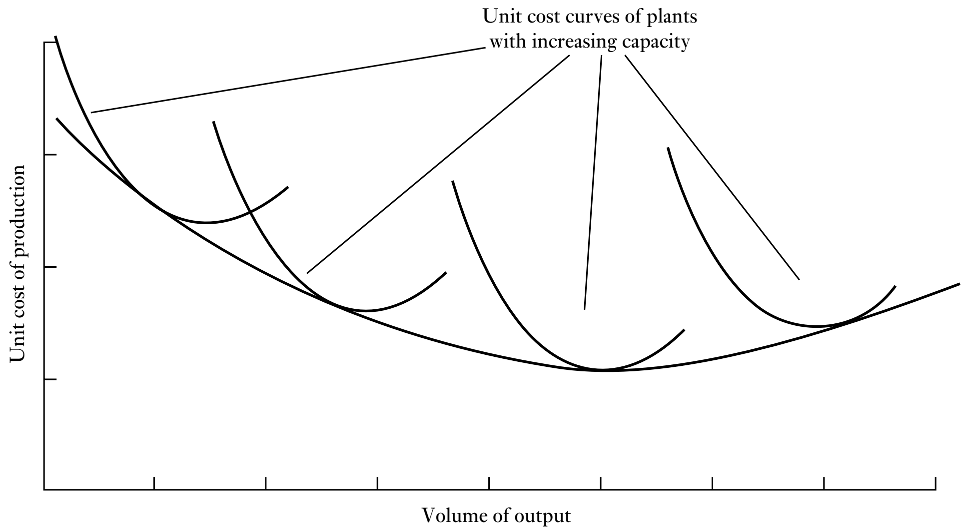


**Figure 1** Unit cost of output curves for plants of varying capacity

become more complex and the pyramid like managerial structures necessary to manage them become likewise more complex. Similarly, the effort of communications and coordination within such structures increases as the number of linkages between each part of the organization increases. Finally, the increasing interdepend ence implied by large units of capacity makes the whole organization vulnerable to disruption if one part of the organization fails (*see* FAILURE MEASURES).

## The Increment of Capacity Change

Large units of capacity also have some disadvan tages when the capacity of the operation is being changed to match changing demand. If an oper ation, whose forecast demand is increasing, seeks to satisfy all demand by increasing capacity using large capacity increments, it will have substantial amounts of overcapacity for much of the period when demand is increasing, which results in higher unit costs. However, if the company uses smaller increments, although there will still be some overcapacity it will be to a lesser extent. This results in higher capacity utilization and therefore lower costs.

The inherent risks of changing capacity using large increments can also be high. For example, if the rate of change demand unexpectedly slows, the capacity will only be partly utilized. How ever, if smaller units of capacity are used, the likelihood is that the forecast error would have been detected in time to delay or cancel the capacity adjustment, leaving demand and cap acity in balance.

A related concept is that of the "capacity cushion." This is the amount of planned cap acity which is above the forecast level of demand in a period. Companies may deliber ately plan for a capacity cushion so that they can cope with aggregated demand even if it turns out to be greater than forecast. Alterna tively, they might judge that extra capacity might be needed to absorb the inefficiencies caused by an unplanned mix of demands on the operation even if the aggregated level of demand is as expected.

The magnitude of any capacity cushion is likely to reflect the relative costs to the organiza tion of having either over or undercapacity. The costs of overcapacity relate to the financing of the capital and human resources that are not being used to produce revenue. The cost of undercap acity is either the opportunity cost of not supply ing demand or the extra cost of supplying demand by unplanned means such as overtime or subcontracting. One suggested approach to quantifying this concept (Hayes and Wheel wright, 1984) is to make the size of any capacity cushion proportional to the following ratio:

$$(C_s - C_x)/C_s$$

where $C_s$ is the unit cost of shortage and $C_x$ the unit cost of excess capacity.

It is suggested that if this ratio is greater than 0.5, a capacity cushion is appropriate, less than 0.5, a "negative cushion" is appropriate. So when $C_x$ is large (as in capital intensive industries), capacity cushions, if they are justified at all, will tend to be small, whereas in industries where $C_s$ is large (because of large profit margins) and $C_x$ is small (because of low capital intensity), a relatively large capacity cushion is likely to be justified.

### The Timing of Capacity Change

An operation also needs to decide when to bring "on stream" new capacity. In deciding *when* the new capacity is to be introduced, an organization must choose a position somewhere between the two extreme strategies of *capacity leading demand* (timing the introduction of capacity in such a way that there is always sufficient capacity to meet forecast demand) and *capacity lagging demand* (timing the introduction of capacity so that demand is always equal to or greater than capacity).

These are "pure" or extreme strategies; in practice, organizations are likely to choose a position somewhere between the two extremes. Each strategy has its own advantages and disadvantages.

Capacity leading strategies have the advantage of always being able to meet demand, therefore revenue is maximized and customers satisfied. Also, most of the time there is a "capacity cushion" that can absorb extra demand or if there are start up problems with new plants. However, utilization of capacity is relatively low, and therefore costs will be high. There are also risks of even greater (or even permanent) overcapacity if demand does not reach forecast levels, and the capital spending on plant is required relatively early.

Capacity lagging strategies always have sufficient demand to keep the plants working at full capacity, therefore unit costs are minimized. Furthermore, overcapacity problems are minimized if forecasts prove to be optimistic, and the capital spending on the plants is later than for a capacity leading strategy. However, there will, for long periods, be insufficient capacity to meet demand fully, resulting in reduced revenue and dissatisfied customers. Also, there would be little or no ability to exploit short term increases in demand, and the undersupply position might be even worse if there are start up problems with the new plants.

A strategy on the continuum between pure leading and lagging strategies can be implemented so that no inventories are accumulated. So all demand in one period is satisfied (or not) by the activity of the operation in the same period. For operations which cannot store throughput, there is no alternative to this. However, for those operations which can, output can be stored for use in the next period. Capacity may be introduced such that demand can always be met by a combination of production and inventories, with capacity more likely to be fully utilized. Because demand is always met and capacity is usually fully utilized, the profitability of the operation is likely to be high. However, the cost of carrying the inventories will need to be funded and the risks of obsolescence and deterioration of stock are introduced.

Whether operations choose a predominantly leading, predominantly lagging, or, if they can, a "smoothing with inventories" strategy will depend on their own circumstances.

See also *aggregate capacity management; capacity management; content of operations strategy; cost; volume*

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### cell layout

*David Bennett*

The usual basic options for laying out facilities are FIXED POSITION LAYOUT, PROCESS LAYOUT, and PRODUCT LAYOUT. A cell layout is actually a hybrid facility arrangement based on combining some of the principles of fixed position and product layouts. A cell layout involves grouping together a number of dissimilar machines or processes according to the design of the product being made or the oper ations required for its production. In this respect a cell layout is similar to a product layout. The main difference, however, is that in a cell layout the operation sequence and flow direction can be varied. Another important difference is that the workers in a cell are usually multiskilled and can operate more than one machine or process, whereas in a product layout they tend to be dedicated to just one task on one workstation. In this respect, therefore, a cell layout draws on one of the features of the fixed position approach.

As with product layouts, a cell layout can be used in high product volume situations, but its use is probably better established in intermittent batch operations. In this case the cell is used to produce PRODUCT FAMILIES rather than a single product and is based on the principles of "group technology." Here the cell (or group of processes) and associated family (or group) of products/parts can be identified using a number of techniques. Among these are coding and clas sification, where products and parts are identi fied by a numerical or alphanumeric coding system, then classified into families and allocated to cells according to their design and processing requirements. Coding systems can be of two types: "universal" systems, which can be applied to all production situations, or "bespoke" systems, which are specifically tailored to the needs of a particular organization. An alternative approach to cell design is to use PRODUCTION FLOW ANALYSIS, where operation route se quence data are analyzed to identify the appro priate combination of product families and processes. However, this technique has the dis advantage of being based on existing products and processes. The ideal approach would be to design all new products specifically for produc tion using a cell layout; this should produce a more efficient overall result.

Originally, cell layouts were associated with the processing of component parts. However, they are increasingly becoming regarded as an appropriate type of layout in connection with assembly work. In this case they are often used for higher product volumes which would other wise necessitate using a product layout. The use of cells overcomes many of the disadvantages associated with product layouts. For example, the wider operator skill requirements provide greater JOB ENRICHMENT, which can result in less absenteeism, lower labor turnover, and easier recruitment. Many of the physical prob lems associated with product layouts can also be overcome using assembly cells; a reduction in workstation interdependency makes the overall system more reliable and the assembly of differ ent product variants is easier with cells than with conventional "line" type product layouts. Cell layouts for assembly also avoid the need for LINE BALANCING, and SYSTEM LOSS.

A further aspect to be considered regarding cell layouts is the use of automation for materials handling and production operations. In cells for producing component parts, industrial robots (*see* ROBOTICS) are frequently used for loading, unloading, and the transfer of material between machines. The processes within a cell can also be automated and computer numerically controlled (CNC) machine tools are often incorporated in production cells. Sometimes the complexity of these cells is such that they can be defined as flexible manufacturing systems (*see* FLEXIBLE MANUFACTURING SYSTEM). In assembly cells an increasingly common form of materials handling device is the automated guided vehicle (AGV), which can transport products both within and between cells under automatic control (*see* AUTOMATED GUIDED VEHICLES). Robots are also starting to be developed with the neces sary dexterity, flexibility, and intelligence to carry out the type of assembly operations which at one time could only be done manually.

The concept of the "cellular" arrangement of facilities has also been used in SERVICE OPER ATIONS. For example, some retail operations might cluster goods in one area, not because the goods are similar in their function but because they conform to a theme recognizable to custom ers. A sports goods area in a department store sells types of goods that might all be available elsewhere in the store, but are clustered around the "sports" theme. This cell like arrangement is sometimes called the "shop within a shop" concept.

Two additional points that warrant discus sion in relation to manufacturing cell layouts are concerned with production control and the payment of workers. As far as production con trol is concerned, cells have the benefit of being a single "planning point," which means that the central planning and control function only needs to be concerned with the cell level rather than the level of each individual machine and process. The cells themselves will have their own individual controllers, which can be com puterized or manual, and will interface with the central planning and control function. In this way the cell can be largely regarded as an autonomous production unit or a focused fac tory. The degree of autonomy involved and the multiskill requirements of cells also demand a more appropriate payment system than that used in other types of situation. Typically, such a payment system will include different elements designed to reflect the characteristics of work carried out in cells.

See also *bottlenecks; business process redesign; div ision of labor; group working; layout; work organ ization*

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## cladistics

*Michel Leseure*

Cladistics is an alternative classification tech nique for manufacturing systems. Initially designed by linguists to model the evolution of languages, it was later applied to biology by Willi

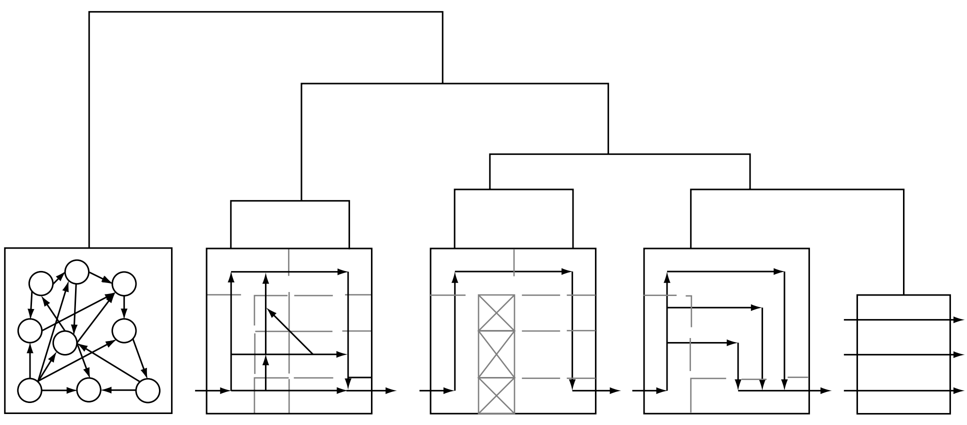

**Figure 1** The evolution of factory layouts in the hand tool industry
From left to right: (1) During the industrial revolution, layout was not optimized in any way. (2) It evolved into a functional layout where several product families are manufactured. (3) When production is restricted to a single product family, a product-based layout, built on the old functional layout, can be observed. (4) Independent product lines are created around core process centers. (5) Process centers are eliminated and the layout is a transfer line.

Hennig and became one of the two most important classification tools used to build the "Tree of Life." Cladistics can be used to describe the evolution of manufacturing systems and describe why certain configurations of core competences are more viable and competitive than others. Figure 1, for instance, shows how factory layouts evolved in the hand tool industry to better match specific business strategies. By understanding how an operational system was designed throughout historical challenges, analysts can map out relevant strategic alternatives and explore positioning options.

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## closed-loop MRP

*Peter Burcher*

Closed loop MRP is a system which grew out of MATERIAL REQUIREMENTS PLANNING (MRP) and which primarily allows plans to be checked against capacity to determine whether they are realistic and achievable. The main plan to which this refers is the MASTER PRODUCTION SCHEDULE (MPS). Also incorporated are the other planning functions of sales and operations, including production planning, resource requirements planning, rough cut capacity planning, and capacity requirements planning. The closing of the loop at the planning stage refers to the checking of the various plans against appropriate resources and feeding back any alterations that may be necessary to the plans. Once these planning phases are complete, the execution functions come into play. These include the manufacturing control functions of input–output measurement, detailed scheduling and dispatching, as well as anticipated delay reports from manufacturing and suppliers. The closing of the loop at these stages involves the feedback from these execution functions so that the planning can be kept valid at all times. Closed loop MRP is the intermediate stage between material requirements planning and MANUFACTURING RESOURCES PLANNING (MRPII).

The production plan is a top level statement of the planned rate of production expressed in aggregate terms, usually by product family (*see* PRODUCT FAMILIES). The units may be physical units of product, standard hours of production, tonnes, gallons, or, most often, sales values of product families. Typically, the time periods are months or quarters, and the planning horizon may be two to ten years. The principal purposes of the production plan are, first, to provide authorization to disaggregate the production plan into specific end items in the MPS; second, to provide the input to resource requirements planning so that decisions can be made on long lead time changes in resources such as plant expansion or acquisition of special purpose equipment. The third purpose may be to stabilize production and employment where demand is subject to seasonal or other variation.

Resource requirements planning is the capacity system at the production planning level. It may make use of historical ratios to determine the resources required to meet the production plan. These might include person hours per unit or sales value of product family, square meters of space required in final assembly as a function of the production rate, cubic meters required in stores per unit of finished product, and so forth. Assumptions must be made concerning the mix of products within families, average sales value per item per product family, or typical products may be chosen as a basis for projecting required resources. If resource requirements planning arrives at an acceptable plan for providing the capacity to produce the production plan, the production plan becomes firm. If this cannot be resolved, the production plan and possibly the long term business and marketing plans will have to be modified.

Analysis of the resources required by the MPS is carried out by rough cut capacity planning (RCCP). Under RCCP, a set of load profiles is maintained for each item scheduled in the MPS. The profiles show the amount of critical resources required to make one unit of the product. The critical resources may be, for example, person power, machine hours, or floor space in certain departments or work centers. These resource requirements are spread by time period over standard lead times.

Once a tentative MPS is developed, it is input to RCCP to determine whether it is compatible with available planned capacity. Load profiles are extended by order quantities, setup hours are added, and the totals are summed across products by time period. If the schedule calls for more capacity than will be available, either plans must be made for increasing the capacity by such means as hiring, overtime, or subcontracting, or the schedule must be reduced. If the schedule calls for less capacity than will be available, the capacity can be reduced by planning for such actions as layoffs, shortened work weeks, or transfer of employees. When inconsistencies between the MPS and planned capacity are resolved, the MPS is made firm.

The RCCP is approximate in that it is only concerned with critical resources and does not take into account changes in work in process or component inventories. However, normally RCCP is sufficient to avoid major inconsistencies between the MPS and available capacity, and remaining problems can be handled at the MRP or operation scheduling levels. "What if" scenarios can be investigated with changes to the MPS using "simulated" rather than live data. The effect of such changes will be reflected in the rough cut capacity plan.

Capacity requirements planning refers to the intermediate range of planning and is confined to the timespan covered by MRP. It is the process of determining how much labor and machine resources are required to accomplish the tasks of production. Open shop orders and planned orders in the MRP system are input to capacity requirements planning, which translates these orders into hours of work by work center by time period by back scheduling from the net requirements due date through the elements of the lead time.

These workloads may be for person power (direct labor load), machine or assembly loads, or indirect labor loads. Analysis of load reports may indicate needed corrections to shop floor capacity. This might entail make or buy decisions (*see* MAKE OR BUY), the planning of alternative routings, subcontracting over long periods of time, the reallocation of the work force, changing the workforce where feasible, and adding additional tooling. If sufficient resources cannot be found at this stage of planning, closing the loop entails feeding back to MRP and the MPS to alter the plans that have caused the overload. This type of capacity planning is referred to as infinite capacity planning since no automatic action is taken to keep within finite resource limits.

Input–output control is the basis for monitoring the capacity plans. Planned work input and planned work output at a work center can be compared to the actual work input and output. This allows the identification of load per work center or group of work centers and any changes to that load. In order to control work in progress levels and hence lead times, the idea is to not release work that cannot be done, but to hold the backlog in the production and inventory control department.

The final stage in closed loop MRP is the detailed scheduling and dispatching on the shop floor. This usually entails the management of queues at the various work centers by means of priority rules which take account of due dates and the work content of orders.

See also *capacity management; JIT/MRP; planning and control in operations*

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## collaborative planning, forecasting, and replenishment

*Pamela Danese*

Collaborative planning, forecasting, and replenishment (CPFR) is the name given to a process of collecting and reconciling the information from diverse sources inside and outside the organization when creating a unified statement of demand. The term emerged during the late

1990s, together with other similar acronyms such as CFAR (collaborative forecasting and replenishment), reflecting a general interest in more collaborative supply relationships where "two or more parties in the supply chain jointly plan a number of promotional activities and work out synchronized forecasts, on the basis of which the production and replenishment pro cesses are determined" (Larsen, Thernoe, and Andresen, 2003). Literature (Hill, 1999; Parks, 1999; Larsen et al., 2003) cites the joint project between Wal Mart and Warner Lambert in 1995 as the first case of implementation of CPFR. The two companies jointly decided to adopt a suited information system to communi cate information to converge toward a single forecast, shared from all the members of the supply network involved in the project. After wards other companies, such as Procter and Gamble, Nabisco and Wegmans, Levi Strauss and Co., and Kmart implemented CPFR initia tives. These pilot cases have evidenced the effectiveness of CPFR in improving the com petitiveness of the whole supply network in terms of improved forecast reliability, higher production efficiency, lower inventory, faster product delivery lead time, and even in terms of increased fill rate. Moreover, in 1998, the Voluntary Inter Industry Commerce Standards (VICS) organization developed a nine step pro cess model as a guideline for CPFR collabor ation. According to this model, the CPFR includes nine implementation steps, which are: (1) the development of a front end agreement (2) the creation of a joint business plan (3) the cre ation of sales forecast (4) the identification of exceptions for sales forecast (5) the collaborative solution of the exception items (6) the creation of order forecast (7) the identification of exceptions for order forecast (8) the collaborative solution of the exception items, and (9) the order generation.

See also *delivery dependability; enterprise resources management; manufacturing resources planning; supply chain integration*

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## competence

*Michael Lewis*

The (organizational) competence perspective is not new, having historical roots in diverse works by, amongst others, Schumpeter (1934), Selz nick (1957), Penrose (1959), Ansoff (1965), and Nelson and Winter (1982). Arguably, however, these disparate elements were only viewed as a perspective when positioned as a corrective to weaknesses (i.e., where's the firm?) in industry analysis frameworks (Porter, 1981). It is perhaps inevitable therefore that the concept is charac terized by conceptual and terminological ambi guities and has been criticized for tautological logic (Porter, 1991). This operations manage ment related definition presents competence as a transformation process combining (Day and Wensley, 1988) resources and activity *inputs* into operational *processes* that result in specific competitive performance *outcomes*.

- *Resources.* Tangible (e.g., machines, facil ities) and intangible resources (e.g., organizational knowledge and external rela tionships; see Nanda, 1996) are the building blocks of any operation. Furthermore, it is important strategically to distinguish be tween "open market" inputs (e.g., fuel, raw materials) and those more unevenly distrib uted resources that introduce ex ante limits to competition (Barney, 1991). Some of these resources can be a more or less direct source of competitive advantage: the posses sion of significant and easily accessible oil or gas reserves, for example, could create a feedstock cost advantage for a petrochemical business (Hart, 1995). Most such resources, however, act in combination to deliver com petitive benefit, such as a seat manufacturer having a site that is geographically close to an auto manufacturer adopting a JIT supply strategy (*see* JUST IN TIME).

- *Strategic resources.* The strategic significance of "barriers to entry" is well established but competence theory argues that sustainable advantage also depends upon "barriers to imitation" preventing advantage being com peted away (Mahoney and Pandian, 1992). It is barriers to imitation that transform scarce resources into *strategic* resources (Werner felt, 1984, 1995). For example, because most resources are only tied "semi perman ently" (Caves 1980: 65) to an operation, sus tainable competitive benefits are only realizable if resources are *difficult to move.* In other words, resources developed in house and/or based on tacit knowledge (Dierickx and Cool, 1989) are more closely "bound" to the firm and cannot be openly traded. Similarly, benefits are sustainable if the resource is also *difficult to copy* or *create a substitute* for. This will depend upon factors such as social complexity (e.g., an engineer only works effectively within a particular team) and experience curve effects (Rumelt, 1984).
- *Processes.* Beginning with resources is im portant for the logic of the conceptual model, but a distinction is drawn between what they *are* and what they *do* (Eriksen and Amit, 1996). In most circumstances it is not resources but *processes* delivering services and products to a market that directly create competitive advantage (Penrose, 1959: 25).
- *Performance outcomes.* If an operation achieves particularly strong *performance out comes* (e.g., lowest cost, highest quality, greatest reliability) in its chosen market(s) and/or is differentiated in what it offers (e.g., producing a unique product range), it creates competitive advantage. In a competi tive context, there is always a time dimension to any performance advantage created (Wil liams, 1992). A firm like Intel, for instance, invests heavily in creating a design and manufacturing performance advantage yet, in its "hypercompetitive" markets, such an advantage will last only a few months. In other words – comparing the long run sur vival of firms to the evolution of biological systems (Nelson and Winter, 1982; Foss, Knudsen, and Montgomery, 1996) – no matter how strongly an operation performs, it can never relax.

### Defining Competence

Following the transformation logic and combing the above elements, competences are those com binations of resource and process that together underpin sustainable competitive advantage for a specific firm competing in a particular prod uct/service market. The advantage thus con ferred is based upon key processes being better than, or different from, those of rivals and sus tainable (the duration of which is dependent upon the industry sector) because the under lying strategic resources are rare, difficult to copy, difficult to create a substitute for, and difficult to move.

### Practical Implications of Competence

It can be argued that competence based models, with their terminological ambiguity and pre dominantly theoretical orientation, have failed to have significant practical impact. This is evi denced by the problematic deployment (Steven son, 1976) associated with the relatively few frameworks that have sought to analyze the stra tegic potential of the inside of the operation (Marino, 1996; Lewis, 2003). This research has revealed a number of dilemmas inherent in the competence model itself. The ex post possession of competence is not unambiguously positive as such strengths can easily become rigidities or "competence traps" (March and Sproull, 1990). In operational terms, this is a phenom enon akin to the benefits of the DIVISION OF LABOR (Foss, 1997: 309) and the disbenefits of overspecialization. With respect to the ex ante analysis of competence, the central role of ambi guity and uncertainty inevitably renders any practical applications much more difficult (Col lis and Montgomery, 1998: 42). More worry ingly, any actual analysis, regardless of its accuracy, can have dysfunctional effects on the operation (Lewis, 2003). As Scarborough (1998: 226) argued: "it does not need Heisenberg's uncertainty principle to remind us that the act of observing organizational phenomena brings about a change in such phenomena." In other words, there may be a paradox that if an oper ation learns too much about its competences, it could actually undermine its overall long term competitive position.

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## computer-aided design

*Michael Lewis*

Computer aided design (CAD) or computer aided design and drafting (CADD) systems apply information technologies to the processes of creating and modifying designs: from drafting of original plans to the virtual testing of com ponents with finite element analysis software. Such systems allow users to move through dif ferent levels of three dimensional design detail and explore system interconnectivity (e.g., how a braking unit fits with a wheel assembly on a car), determine the effects of different tolerances, de termine loads and stresses, and so on, all without the need to build prototypes. Today, the design of ever smaller and yet more complex microelec tronic devices would be simply impossible with out CAD. The digitization of the design process also enables a design library to be built up that can dramatically increase the productivity of the process. The label first emerged to differentiate such systems from traditional drawing offices, but they are increasingly ubiquitous as, with the ever increasing power of computing, sophisti cated CAD technologies that were once the pre serve of major corporations are now widely available for most PC systems.

See also *advanced manufacturing technology; computer integrated manufacturing; design; flex ible manufacturing system; process technology*

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## computer-integrated manufacturing

*David Upton*

Computer integrated manufacturing (CIM) is a generic term (compare with ADVANCED MANUFACTURING TECHNOLOGY) used to describe the integration of manufacturing processes via increasingly sophisticated informa tion/communication technology (ICT) infra structures (e.g., distributed server technology, enterprise resource planning software, common databases, etc.). At its heart CIM brings together two key aspects of manufacturing activity: ma terials processing and information processing. Automation has already had a major impact on many of the physical transformation processes. CIM moves the emphasis toward indirect activities, many of which involve information processing or communication. Enhanced "connectivity" also enables further blurring of the distinctions between functions, e.g., in the case of COMPUTER AIDED DESIGN (CAD) and manufacturing (CAD/CAM), where digital data used to create and manipulate a product design is passed directly to the digitally controlled machinery required for producing it.

Such integration does not necessarily stop at the boundaries of the firm. Integration via elec tronic means can also extend backwards along the supply chain (with, for example, shared design processes or electronic components ordering linked to INVENTORY MANAGE MENT computers) or forwards into the distribu tion channel, to speed the flow of products to outlets, while also reducing the inventory held within the chain. Older, proprietary systems used "electronic data interchange" (EDI) to achieve this, but more recently there has been an explosive growth in the development of Inter net based standards to achieve similar connect ivity across a much broader range of firms and activities.

Most models of CIM involve some form of stepwise or hierarchical arrangement of control, from low levels where individual elements (ma chine controllers, data collectors, etc.) operate autonomously but also communicate informa tion to the next level that is responsible for the overall monitoring and control of a level (e.g., a manufacturing cell). Further up, a plant control ler would handle the activities of several cells, coordinating their use of resources and monitor ing their overall performance. Level four would involve the integration of other key functional areas, e.g., design and sales, and would represent a shared information system of the kind repre sented by MANUFACTURING RESOURCES PLANNING (MRPII). Level five would be an overall business systems integration, in which the financial and sales information would be linked into the manufacturing system. This level of integration is commonly achieved through enterprise resource planning (ERP) systems (*see* ENTERPRISE RESOURCES PLAN NING).

A key enabling technology in all of this is the computer network, which has the important architectural property that information can be shared throughout the system. Changes any where in the system will update the rest of the information in the system; thus the entire oper ation can be seen to behave as if it were a single, enormously complex machine. This is not, however, simply a centralizing and concentrat ing process; the key property of the networks that form the "nervous system" for CIM is the ability to be simultaneously highly centralized and highly decentralized. Thus the economies of shared resources and information can be added to those of local autonomy and flexibility in uncertain environments.

CIM exemplifies the distinction between "substitution" innovation and innovation that enables new, competitively powerful activities to be conducted, e.g., the ability to deliver custom products with rapid response (as described in Upton, n.d.). CIM also differs from other technologies in having potential impact on indirect cost areas as well as direct costs. It contributes to better coordination; it tightens the linkages between previously separ ate elements in a production chain; it brings powerful planning and monitoring tools to bear upon the problems of production control; and it reduces the amount of paperwork required to maintain even a simple manufacturing system. Thus many of the traditional areas of overhead cost (which can often account for 40 percent or more of total product costs) can be reduced, adding further to the competitive benefits offered by CIM.

See also *e business; flexible manufacturing system; process technology; robotics; supply chain manage ment*

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### concurrent engineering

*Michael Lewis*

Concurrent engineering is the term commonly applied in a manufacturing/engineering context to the process of overlapping design and other working activities (normally underpinned by in creasingly sophisticated information/communi cation technology (ICT) infrastructure) in order to achieve reduced development lead times and improved quality and reduced costs. During the 1990s a number of different studies of develop ment projects (e.g., looking at Japanese automo tive design practices; Clark and Fujimoto, 1989, 1991) highlighted overlapping the phases of product development as a critical factor that assisted so called "world class" firms in redu cing total development cycle time.

See also *computer aided design; design chain management; quality function deployment; simultaneous development*

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### condition-based maintenance

*Michael Shulver*

Condition based maintenance (CBM) is a pro active approach to maintaining physical facilities that forms a core part of effective QUALITY MANAGEMENT SYSTEMS. A CBM program coordinates intervention in production processes – before breakdown occurs – to either repair or replace parts based on some form of ongoing status monitoring. The technique was pioneered in high volume or continuous flow processes where assets have to be run for long periods in order to achieve high utilization.

CBM can involve monitoring any characteris tic of the equipment that might indicate its con dition. For example, vibration might indicate the wear characteristics of a machine tool, especially when the vibration is measured near bearing positions. The lubrication oil in machines might be sampled and tested spectrographically for particle contamination in order to indicate the likelihood of failure in the immediate future. Temperature in electric motors might indicate the efficiency, and therefore condition, of the motors. Typically, the results of this monitoring are then analyzed and used to decide whether the equipment should be stopped and repair effected.

The principle of condition based monitoring extends beyond technology based equipment. Simple routine inspection of furniture or floor coverings at leisure facilities, for example, could be regarded as CBM if the results of such in spections were used to take the decision as to whether to refurbish or replace facilities.

See also *maintenance; preventive maintenance; reliability centered maintenance; total productive maintenance*

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### content of operations strategy

*Nigel Slack*

The content of operations strategy is the collec tion of policies, plans, and behaviors that an organization chooses to pursue in its operations function. It is the definition of how the company expects to use its operations resources to con tribute to its strategic direction. The content of operations strategy is usually contrasted with the "process" of operations strategy formulation, i.e., the way in which content is determined.

Content decisions can be classified in several ways according to the classification of OPER ATIONS ACTIVITIES that is adopted. The most common is to distinguish between the stra tegic level decisions that determine the oper ation's structure and those that determine its infrastructure. Typical structural decisions in clude the amount, timing, and type of capacity, the size, type, and location of facilities, the type of PROCESS TECHNOLOGY to develop, and the direction, extent, and balance of VERTICAL IN TEGRATION. Typical infrastructural decisions include determining the development of the workforce, the organization of quality policy, the type of production planning and materials control, and the organization structure of the manufacturing function (Hayes and Wheel wright, 1984).

Other classifications may adopt different cat egories of operations strategy decisions. Slack and Lewis (2002) classify content decisions as follows:

- Capacity, including facilities in general.
- Supply networks, including purchasing and logistics.
- Technology, the process technology that produces goods and services.
- Development and organization of the oper ation's processes.

Between them these decisions define the scope and nature of the resource base of any organiza tion. However, the boundaries between oper ations strategy decisions in these four areas are not clean. For example, decisions on capacity location are influenced by the choice of suppliers in the supply network, the extent of vertical integration is determined partly by the nature of the process technologies involved, the organ ization structure of the operation is influenced by the size of operating locations, and so on. Furthermore, the exact nature of the decisions will depend on the nature of the organization. However, this relatively straightforward cat egorization allows the examination of each set of decisions in turn, even if it is necessary to remember the interconnections between them.

Furthermore, a simple dichotomy between STRUCTURAL AND INFRASTRUCTURAL DE CISIONS is sometimes seen as too much of a simplification. Not that the distinction itself is inappropriate. What is at fault is the tendency to categorize decision areas as being either entirely structural or entirely infrastructural. In reality all decision areas have both structural and infra structural implications. Capacity strategy, since it is concerned with the physical size and loca tion of operations, is mainly a structural issue. However, both size and location can affect the organization's reporting relationships systems and procedures. Similarly, supply network deci sions have much to do with the configuration of an operation's resources in terms of what the organization chooses to perform in house and what it chooses to buy in. But buying products and services from outside the organization im plies the need for infrastructural support for communications and the development of rela tionships. Process technology, likewise, has its structural aspects. The physical size, shape, and attributes of process technology partly deter mine the physical form of the operation. Much of an operation's process technology, though, will be devoted to driving the systems, proced ures, and monitoring systems that form its infrastructure. Even decisions within the devel opment and organization category, while pri marily being concerned with infrastructure, can have structural elements. A set of reporting re lationships embedded within an organizational structure may reflect different locations and dif ferent process technologies. It may be more ap propriate to consider a spectrum where, at one end, capacity related decisions are largely struc tural to, at the other end, development and or ganization related decisions which are largely infrastructural.

See also *generic manufacturing strategies; manu facturing strategy process; operations strategy; order winners and qualifiers*

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### continuous improvement

*Harry Boer*

Continuous improvement is an approach to im proving the performance of operations which promotes frequent, regular, and possibly small incremental improvement steps. Although con tinuous improvement is not concerned with pro moting small improvements *per se*, it does see small improvements as having a significant ad vantage over large ones in that they can be followed relatively easily by other small im provements. Large steps in improvement, on the other hand, usually require a pause for con solidation between steps.

Continuous improvement is also known as *kaizen*, a Japanese word meaning "improve ment."

> Moreover it means improvement in personal life, home life, social life and work life. When applied to the workplace *kaizen* means continuing improvement involving everyone managers and workers alike. (Imai, 1986)

In continuous improvement it is not the size of each step that is important. Rather, it stresses the likelihood that improvement will be ongoing. Put another way, the *rate* of improvement is less important than the *momentum* of improve ment. What matters is that some kind of im provement has actually taken place.

Continuous improvement as a philosophy is often contrasted with BREAKTHROUGH IMPROVEMENT. Breakthrough improvement places a high value on creative solutions. It en courages free thinking and individualism. It is a radical philosophy in so far as it fosters an ap proach to improvement that does not accept many constraints to what is possible. "Starting with a clean sheet of paper," going back to first principles, and "completely rethinking the system" are all typical breakthrough improve ment principles. Continuous improvement, on the other hand, is less ambitious, in the short term. It stresses adaptability, teamwork, and at tention to detail. It is not radical, as such; rather, it builds upon the wealth of accumulated experi ence within the operation itself, often relying primarily on the people who operate the system to improve it. A frequently quoted analogy is the difference between the sprint and the marathon. Breakthrough improvement is a series of explo sive and impressive sprints, whereas continuous improvement, like marathon running, does not require the short term strength essential for sprinting; however, it does require persistence and perseverance.

Notwithstanding the differences between breakthrough and continuous improvement, it is now widely held that it is possible to combine the two, albeit at different times. Large improve ments can be implemented as and when they seem to promise significant gains, but between such occasions the operation can continue making its quiet and less spectacular *kaizen* improvements.

See also *business excellence model; DMAIC cycle; PDCA cycle; sandcone model of improvement*

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### continuous replenishment programs

*Pietro Romano*

When sales occur through retailers, there are several industry practices that result in single point control of replenishment. In continuous replenishment programs (CRP), the wholesaler or manufacturer replenishes a retailer regularly based on point of sale (POS) data. The CRP could be supplier, distributor, or third party managed. In most instances, CRP systems are driven by actual withdrawals of inventory from retailer warehouses rather than POS data at the retailer level. In fact, this is easier to implement, and retailers are often more comfortable sharing data at this level.

### cost

*Nigel Slack*

The meaning, measurement, and management of cost have long been primary concerns of operations management (OM) practitioners and academics. Conceptually, cost is closely related to PRODUCTIVITY, but whereas productivity is concerned with the way inputs are transformed to outputs, cost refers to the monetary value of the resources used to produce goods or services. Two management issues are of concern to most operations managers. First, how to identify and measure the costs associated with the production of particular goods or services; this is an issue primarily within the province of management accounting but, put simply, an operation will generally spend "its" money on staff, facilities, technology, equipment, and material costs. Second, what strategic and operational factors influence the production costs of goods and services?

#### Strategic Influences on Cost

The advent of mass manufacturing was driven in large part by aggregate consideration of the effect that production volume has upon unit cost. In theory the effects of this are straightforward. Figure 1 shows how average costs are supposed to reduce as volume increases, according to the formula:

Average cost = total cost/output
= fixed costs/output + variable costs/output
= fixed costs/output + variable cost/unit

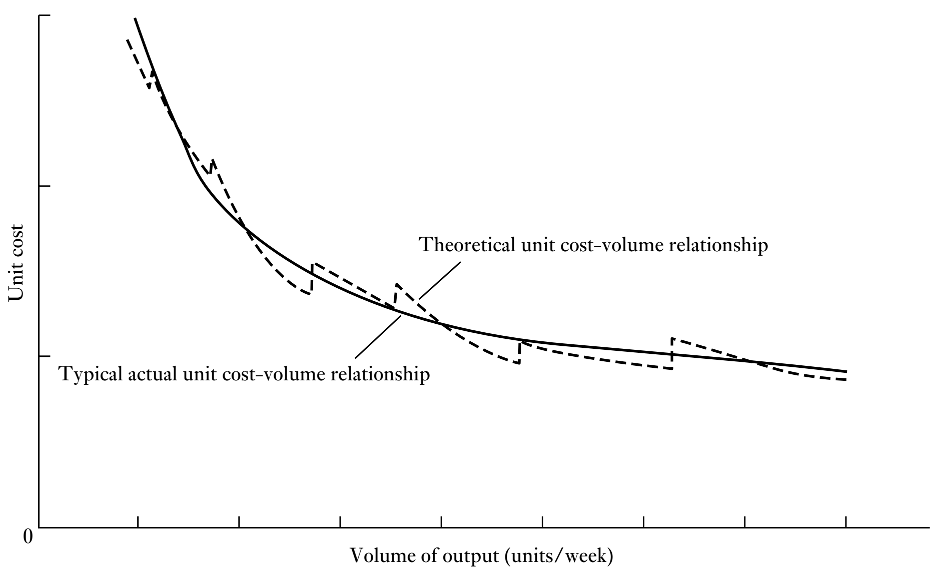


**Figure 1** Unit cost of output varies as volume of output varies

In some operations such as some process in dustries, cost–volume curves do approach that shown in figure 1. However, for most operations this is a simplification, since operations usually accommodate changes in volume through a series of relatively small discontinuities in the cost curve, e.g., shedding labor and subcontract ing when output reduces or starting up produc tion lines as output increases. Further, nominal capacity is not usually the definite cutoff point implied by figure 1.

Capacity is rarely so well balanced between every part of the production process that it all reaches its limit at the same level of output, so BOTTLENECKS occur as demands are placed on some parts of the operation more heavily than on others. This means that each part of the oper ation has to incur fixed cost steps as it attempts to balance capacity. The result is that in most operations the volume–cost curve is neither smooth nor entirely predictable because there is some management discretion as to when to commit the operation to fixed cost breaks.

In the longer term the volume of output may allow changes in the way an operation either uses its existing technology or acquires new types of technology. Opportunities in the way technol ogy is used derive from the effective variety placed on parts of the operation. As volume increases, the tendency is for variety per unit volume to decrease, so each part of the operation has fewer different tasks to perform per time period. This is likely to reduce the number of changeovers necessary, which will in turn release the capacity previously spent changing from one activity to the next, and avoid the quality prob lems associated with changeover. More signifi cantly, it may allow more dedicated technology to be developed where economies derive from focused specialization on a narrow set of tasks.

Variety is often a less well understood driver of cost than volume. High product or service variety often means high parts variety, process variety, and routing variety, behind which is the complexity that is the root cause of variety re lated costs. First, high variety requires more complex technology, or alternatively makes it more difficult to develop the dedicated technol ogy that may keep costs low. Second, high var iety loaded onto plant and equipment usually leads to higher capital and operating costs be cause of the increased complexity of control systems, materials handling, and adjustment mechanisms, together with changeover down times.

In the same way as for volume driven costs, the relationship is neither smooth nor static. There are often "variety breaks" where an incre mental increase in variety cannot be borne by existing technology, although this is less true for many newer process technologies, which are changing some aspects of the relationship be tween variety, flexibility, and cost. Variation, which is the degree to which the demand placed on the whole operation fluctuates over a period of time, also affects an operation's costs. One way of understanding the variation–cost rela tionship is to imagine a perfectly steady demand. All customers demand exactly the same level and mix of products or services every week of the year. The costs saved under such an ideal, and hypothetical, condition are the costs associated with variation. The exact source of these vari ation driven costs will depend on how an indi vidual operation chooses to treat fluctuations in demand. The choices available are part of the AGGREGATE CAPACITY MANAGEMENT activity.

## Operational Influences on Cost

The benefits of achieving high levels of perform ance in the other performance objectives of QUALITY, speed (*see* TIME BASED PERFORM ANCE), DELIVERY DEPENDABILITY, and FLEXIBILITY can be viewed as having both external and internal aspects. Externally, per formance is valued by customers for the en hanced levels of product or service specification or levels of services it brings. Internally, high levels of performance bring benefits which are seen primarily in terms of their effect on cost.

- A higher quality performance reduces cost, where "quality" is used to mean conform ance to specification. Fewer errors within the operation directly reduces rework, scrap, and waste as well as resulting in fewer unplanned activities, which in turn leads to greater internal dependability. Fur ther, error free operation enhances an oper ation's ability to reduce throughput time, which in turn reduces costs.

- Fast throughput reduces cost because material information or customers that move quickly through an operation spend less time in inventory, attract fewer overheads, and make forecasting easier. Fast throughput also encourages dependable delivery since small deviations from schedule can be accommodated faster.
- Internal delivery dependability reduces cost because it reduces the level of uncertainty in the operation. If all materials information and customers transferred within the operation exactly as planned, the overhead devoted to monitoring and progressing late deliveries is eliminated, as is all the effort of rescheduling resources in order to accommodate the late delivery. Also, without internal dependability there is little chance of success in trying to speed up throughput.
- Greater flexibility often can reduce costs directly by letting the operation change from producing one product or service to another with little loss of output, e.g., by increasing changeover flexibility (*see* SETUP REDUCTION), and indirectly, by reducing throughput time which, in turn, reduces costs. Flexibility can also increase internal dependability, by allowing an alternative process route to bypass a breakdown, for example, which in turn reduces cost.

See also *activity based costing; capacity strategy; economic order quantity; focus; performance measurement; process technology; volume*

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## critical chain

*Harvey Maylor*

Projects that run late, over budget, or fail to meet key needs of their stakeholders cause considerable problems for businesses, governments, and individuals. A basic analysis suggests that either the methods being used for project management or their application, or both, must be at fault. Given the number of project failures, questions do arise about the methods being used, in particular that they are not sufficiently *robust* to the uncertainty of the project environment. Moreover, many of the traditional methods of project planning, such as PERT (*see* NETWORK TECHNIQUES), are useful for quantifying uncertainty but do little to help manage it. The situation is exacerbated by the facts of the behavior of people in projects. These are:

1. All goals are based on estimates, which contain uncertainties. These include the myth of the Gaussian distribution in planning – that activities will have a most likely time and the actual time taken could be either side of this. The reality is that activities will sometimes run to time, often late, but almost never early.
2. Estimates of activity times generally include a large safety margin – people will estimate according to their worst past experience of that type of activity, but this safety margin at each activity does not help in achieving on time completion, because of (6) below.
3. Network diagrams (A o N) usually contain a latest start time for activities. For non critical activities, this builds in slack at the start of activities. Perversely, this creates a situation where these activities, if started at their latest start times (as cash flow pressures often wrongly dictate), also become critical. The more critical paths in a project, the greater the chance of failing to meet time goals, and the less chance of "focus" that the project manager will have.
4. Because of this method of scheduling activities, the situation arises where "a delay in one step is passed on in full to the next step. An advance in one step is usually wasted" (Goldratt, 1997). Worse still, where there are parallel activities, regardless of an early finish in one of the paths, the biggest delay is passed on to the subsequent activities.
5. The way that we measure progress is in error – generally, by the time that a project man

ager is notified of a problem, it is already too late to prevent it having an impact.

6 Related to (3) and (4) above, *student syndrome* is identified as a situation where, despite people being given extra time (slack) for an activity, the extra time is wasted at the front end, and the activity often won't be started until the latest possible time.
7 It is usual in business projects for people to have to multitask. The effect of this is to increase the lead time for all the projects.

The alternative is to use an application of the theory of constraints (TOC) approach, which in a project are:

- the critical path of the project;
- the resources that are on the critical paths of one or more projects;
- dates that are fixed into the schedule and cannot be moved.

The critical path is only one of the constraints. In practice:

1 The schedule is calculated in the traditional method using critical path analysis (CPA).
2 The activity times are reworked, removing any non active time (the difference between the elapsed time and the time someone is actually working on the activity).
3 The network is recalculated, with the new, shorter times.
4 The difference is a *buffer*, which is used to protect the constraints that form this critical chain: the critical path, critical re sources, and any interim deadlines that, if missed, would obstruct the progress of the project.

See also *project control; project management; pro ject trade offs*

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http://www.ProChain.com.

**critical incident technique**

*Robert Johnston*

Critical incidents are events that contribute to, or detract from, perceived service or product performance in a significant way. For an inci dent to be defined as critical it must deviate significantly, either positively or negatively, from what is normal or expected. Critical inci dent technique (CIT) was originally developed during World War II by psychologist John Fla nagan and used to determine the reasons for the high rate of pilot failure during training. The analysis of his tests provided the basis for selec tion tests that achieved a substantial reduction in failure rate. Today CIT is applied in a wide variety of settings including disaster manage ment, transport assessment, stress management, medicine, and counseling and is becoming a popular technique in SERVICE OPERATIONS research to better understand customer expect ations (*see* QUALITY CHARACTERISTICS), per ceived quality (*see* SERVICE QUALITY), and to help managers develop approaches to quality improvement. CIT, as applied to service en counters, usually comprises two questions: the first asks customers to think of a time when they felt very pleased and satisfied with the service/product received and to describe, in a few sen tences, the situation and why they felt so happy; the second requires customers to think of a time when they were unhappy and dissatisfied with the service/product they received and to de scribe, in a few sentences, why they felt this way.

This technique is quite unlike scale item ques tionnaires, which usually measure perceptions against predetermined factors. CIT allows cus tomers to express their own views without preju dice. Thus, CIT provides an understanding of quality from a customer's point of view (cus tomer perceived quality). As the technique col lects the interpretation of events by customers, in their own words, the anecdotes may be a valuable source of information to help managers understand how they might improve service quality.

There are three key disadvantages in using this technique. First, the incidents may have taken place some time before the collection of the data and so they may have been reinterpreted in light of further events. Second, CIT requires customers to take more time and effort than, for example, ticking boxes, so the response rate tends to be quite low. And, third, the classification and interpretation of data can be a considerable task.

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## Crosby

*Rhian Silvestro*

Before gaining his reputation as a quality consultant, Philip Crosby served in the navy, became quality manager on the first Pershing missile program, and was ITT's corporate vice president with responsibility for quality. Crosby's approach to quality improvement was popularized through his book *Quality is Free* (1979), so entitled because Crosby's contention was that it is not producing high quality goods and services that is costly but, rather, failing to produce goods and services right first time.

Crosby's philosophy is encapsulated in his four "absolutes of quality":

1 Quality is defined as conformance to requirements, where requirements are defined by the customer.
2 The system for causing quality is prevention, not appraisal.
3 The performance standard must be zero defects.
4 The measurement of quality is the price of non conformance (PONC).

Crosby estimates that the cost of non conformance is typically between 25 and 40 percent of operating costs and promotes the measurement of PONC as a necessary step toward quality improvement. He argues vehemently against the concept of "acceptable quality levels," which can lead to acceptance of poor quality and undermine the performance standard of zero defects. He also proposes a 14 step approach to quality improvement, recommending that implementation be led by a steering group of senior managers and be realized through the activities of cross functional quality improvement teams.

See also *Deming; Feigenbaum; Juran; quality; total quality management*

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## cross-docking

*Pietro Romano*

Cross docking is a distribution strategy that Wal Mart made famous. In this system, warehouses function as inventory coordination points rather than as inventory storage points. In a typical cross docking system, goods arrive at a warehouse from the manufacturer, are transferred to vehicles serving the retailers, and are delivered to the retailers as rapidly as possible. Goods spend very little time in storage at the warehouse – often less than 12 hours, sometimes less than an hour. Cross docking is attractive for two main reasons. First, cross docking can save money by avoiding costly moves to and from shelves in the warehouse, thus it is used frequently to minimize labor costs and handling in warehouses and distribution centers. Second, for less than truckload (LTL) and small package carriers, cross docking is a way to reduce transportation costs and a way to consolidate those shipments to achieve truckload quantities. On the other hand, cross docking systems require a significant start up investment, are effective only for large distribution systems, and can be very difficult to manage.

**customer support operations**

*Michael Lewis*

Customer support operations comprise those activities which firms undertake to support cus tomers in the post purchase use and mainten ance of their product: in business to business markets this has traditionally meant, as a min imum, the management of spares but increas ingly includes the provision of, for instance, call centers or websites offering services ranging from advice (e.g., FAQs) to the dispatch of field agents to assist customers with routine and non routine repairs/replacement of equip ment (Armistead and Clark, 1992; Mathe and Shapiro, 1993; Mathieu, 2001b). Although often viewed in the past as a "necessary evil" – to insure sales, satisfy warranty requirements, etc. – more and more manufacturing companies now regard their "customer service and support" processes as central to their competitive survival, because that's "where the money is" (Wise and Baumgartner, 1999). This trend is particularly pronounced in firms where a combination of elongated product life cycles, increased compe tition, and/or market saturation have severely restricted the potential growth from new prod uct sales. In such markets (table 1), the strategic focus is increasingly shifting to leveraging value from an "installed base" (IB) of equipment that is often an order of magnitude larger than annual new equipment (NE) sales.

Given such data it is unsurprising to note that firms in these sectors have been particularly active in moving "upstream": e.g., 50 percent of Rolls Royce overall revenues came from ser vice activities in 2002; likewise two of the five global "elevator" players, Thyssen Krupp and Kone, declared 50 percent and 57 percent, re spectively, of their overall revenues from ser vices. There are a number of buyer and supplier factors influencing the increased stra tegic importance, and correspondingly the scale and scope, of product customer support services. From a buyer perspective, for example, a more sophisticated approach to procurement and pur chasing, influenced in part by the QUALITY movement (e.g., W. E. Deming's exhortation to "never purchase on price alone"), means there is more interest in total life cycle costs, which in clude reliability factors such as cost of failure, maintenance, upgrades, etc. From a supplier perspective, long term service contracts can (theoretically, at least) provide some insulation from the economic cycles that traditionally drive capital investments, and once the "service or ganization is in place, it becomes a fixed cost and the main driver of profitability is capacity util ization. Established ... contracts reduce the variability and unpredictability of demand over the installed capacity, and allow higher average capacity utilization" (Oliva and Kallenberg, 2003: 168).

Generic trends aside, different firms adopt different service and support strategies, depend ent upon the nature of the product, the capabil ities of the supplier, the type of customer, the sophistication of their requirements, etc. Al though by no means comprehensive, the extant literature (e.g., Armistead and Clark, 1992; Mathieu, 2001a, b; Oliva and Kallenberg, 2003) suggests customer support activities can be grouped under two broad categories:

1 *Product related.* Capturing information regarding product usage and then integrate any relevant findings so they influence the design of the next generation of products (or upgrades, etc.).

**Table 1** IB/NE ratios in selected capital goods sectors

| *Civil aircraft (US 1999)* | *Tractors (US 1999)* | *Elevators (world 2002)* | *Locomotive (US 1999)* | *Automotive (US 1999)* |
|---|---|---|---|---|
| 150/1 | 30/1 | 23.8/1 | 22/1 | 13/1 |

2 *Service related*. Looking beyond the func tionality and performance of the product to address customer concerns with respect to broader customer expectations, timing, speed of response, the nature of the re sponse: "clients want more value and this value is connected to the use and perform ance of systems; they want solutions more than just products or services; they want to take advantage of their supplier's know how and not just their product; they want an integrated and global offering and are reluc tant to do business with several suppliers; finally, they want customized relationships" (Mathieu, 2001a).

See also *new product development process; product service systems; service design; service operations; service processes*


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# D

## delivery dependability

*Nigel Slack*

Delivery dependability means keeping delivery promises. Although speed and dependability are two halves of delivery performance, they are fundamentally different in as much as speed is usually quoted and defined as part of the specification for the order whereas dependability is often assumed (although customers may attempt to encourage dependability by the use of penalty clauses for late delivery, etc.). Dependability has a number of attributes in common with QUALITY. It is a "conformance" measure, but conformance to time rather than specification. It is also an attribute which influences customer satisfaction over the longer term rather than one which necessarily insures an immediate sale.

### Measuring Delivery Dependability

In principle dependability is a straightforward concept, where

$$\text{Dependability} = \text{due delivery date} - \text{actual delivery date}$$

When delivery is on time the equation will equal zero; a positive measure means delivery is early and negative means delivery is late. However, measurement is not always so straightforward. For example, the "due date" can mean the date originally requested by the customer or the date quoted by the operation. Also there can be a difference between the delivery date scheduled by the operation and that which is promised to the customer. Nor are delivery dates immutable; they can be changed, sometimes by customers but more often by the operation. If the customer requests a new delivery date this may be used to calculate delivery performance.

### The Benefits of Delivery Dependability

It is important to distinguish between the external and internal benefits of delivery dependability. Externally, it has often been viewed as a "qualifying" performance objective (something that only becomes apparent after a contract is signed and deliveries have started; *see* ORDER WINNERS AND QUALIFIERS), but increasingly operations can "win" business by being more dependable in delivery: more and more operations operate in a JUST IN TIME environment and are becoming more sophisticated in their buying behavior. The most significant internal benefit of dependability is the stability it gives. In a highly dependable operation relatively little is wasted on coping with unexpected events. Perhaps more significant is the reduction in the fragmenting effects of continuing interruptions to routine operations and the absence of a lack of trust in the internal working of the operation. Operations managers can "keep their eye on the ball." From this stability can come other benefits, most notably less inventory. Part of the reason for the buildup of inventory between stages in an operation is that it buffers each stage from the output variation of its neighbors. In process inventory is often justified on the basis that internal deliveries might not be on time and therefore inventory is required to protect the operation. However, with increased dependability there is no need for the "insurance" of buffer inventory.

### Improving Delivery Dependability

A number of prescriptions exist for improving the external and internal dimensions of delivery dependability. Most commonly a link is drawn between dependable delivery and dependable technology. The effectiveness of any operations maintenance practices (*see* MAINTENANCE) will clearly affect internal, and therefore external, dependability. Other generic prescriptions in clude the following.

- *Plan ahead*. Often when a delivery is late the root cause will be some occurrence which was unexpected by the operation. Fre quently the unexpected event could have been predicted with some internal mechan ism that looks forward for indications of possible trouble.
- *Do not overload capacity*. Loading an oper ation above its operational capacity often results in missed internal delivery dates. The consequences of excess load may be a lack of control and overlooked due dates.
- *Flexibility can localize disruptions*. Certain types of flexibility can service to localize disruptions when they do occur, by provid ing alternative processing capability. Flexi bility does not prevent disruption, although it can limit its effects.
- *Monitor progress closely*. A common cause of lateness seems to be overlooked internal de livery dates. Every day that internal lateness is not recognized is a day less in which to do something about it. An internal monitoring system may become self reinforcing because when internal dependability increases and flow becomes more predictable, it is easier for internal customers to signal late deliver ies.
- *Emphasize internal supplier development*. Ini tially the role of internal customers may be to monitor the delivery performance of their suppliers. Later it may be a matter of im proving communications, e.g., holding joint improvement team meetings and so on.

See also *cost; collaborative planning, forecasting, and replenishment; flexibility; life cycle effects*

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## Deming

*Rhian Silvestro*

W. Edwards Deming became highly influential as a consultant in Japan in the 1950s, when he was invited to lecture at the Japanese Union of Scientists and Engineers (JUSE) on quality con trol methods. By the 1980s his methods had achieved widespread recognition in the West.

Deming called into question the traditional view that there exists a trade off between qual ity and PRODUCTIVITY (*see* TRADE OFFS). He argued that improved quality leads to re duced rework, fewer delays, better utilization of resources, and hence improved market share and long term business survival. Although de fining quality in terms of uniformity and de pendability, Deming was emphatic about the importance of focusing the whole organization on customer needs. He identified two key con tributors to process variability: "common causes," which relate to weaknesses in the man agement systems, and "special causes" due to individual machines or operations. He pro moted the use of statistical methods to identify the special causes and analyze and improve production processes, whilst his renowned "14 points for management" were intended to ad dress the common causes (see table 1). He also identified seven common obstacles to quality improvement ("the seven deadly diseases"), and argued that poor management rather than incompetence on the part of workers causes 94 percent of quality problems.

Deming stressed the importance of never ending, CONTINUOUS IMPROVEMENT. His improvement cycle, based on earlier work by the statistician Dr. W. Shewart, consisted of four stages: plan (identify goals and performance measures), do (implement the plan), check (review progress against plan), and act.

**Table 1** Deming's 14 points for management

| | |
|---|---|
| 1 | Create constancy of purpose toward improvement of product and service. |
| 2 | Adopt the new philosophy. We can no longer live with commonly accepted levels of delays, mistakes, defective materials, and defective workmanship. |
| 3 | Cease dependence on inspection. Require, instead, statistical evidence that quality is built in. |
| 4 | End the practice of awarding business on the basis of price tag. |
| 5 | Find problems. It is management's job to work continually on the system. |
| 6 | Institute modern methods of training on the job. |
| 7 | Institute modern methods of supervision of production workers. The responsibility of foremen must be changed from sheer numbers to quality. |
| 8 | Drive out fear, so that everyone may work effectively for the company. |
| 9 | Break down barriers between departments. |
| 10 | Eliminate numerical goals, posters, and slogans for the workforce asking for new levels of productivity without providing methods. |
| 11 | Eliminate work standards that prescribe numerical quotas. |
| 12 | Remove barriers that stand between the hourly worker and his right to pride of workmanship. |
| 13 | Institute a vigorous program of education and retraining. |
| 14 | Create a structure in top management that will push every day on the above 13 points. |

*Source*: Deming (1986).

See also *Crosby; Feigenbaum; Juran; PDCA cycle; quality; total quality management*

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## dependent and independent demand

*Nigel Slack*

An operation that produces components which go into an assembled product need not treat demand as a totally random variable: it knows that it is *dependent* upon the demand for the finished product. The process of determining dependent demand is also relatively straightforward. In the example given, it will consist of examining the manufacturing schedules for the assembled product and deriving the demand for the part from these. For every finished assembly that is to be manufactured on a particular day, it is simple to calculate that the number of parts that will be demanded by the assembly plant on that day is the number of assemblies produced multiplied by the number of parts per assembly. MATERIAL REQUIREMENTS PLANNING (MRP) is one such dependent demand approach.

Conversely, *independent* demand is less predictable because its underlying causes are, by definition, not fully understood. In such circumstances, demand must be treated to a certain extent as random and operations have little choice but to take decisions on how they will supply demand without having any firm forward visibility of customer orders. They must make planning and control decisions based on demand forecasts and in light of the risks they are prepared to run of being unable to supply demand. Independent demand planning and control makes "best guesses" concerning future demand, attempts to put the resources in place that can satisfy this demand, and attempts to respond quickly if actual demand does not meet forecasts. Conventional INVENTORY MANAGEMENT (and forecasting) systems are usually based on an assumption of independent demand.

See also *P:D ratios*

## design

*James Moultrie*

It is difficult to identify a precise definition for an amorphous concept like design. In an oper ations management context, design can be used as a verb to describe the activities required to translate an idea or an identified need into a physical artifact or a service process. Used as a noun, design can also refer to the physical arti fact or service specification that emerges as a result of this process.

See also *design chain; design–manufacturing interface; new product development process; orga nization of development; quality function deploy ment; service design; Taguchi methods; value engineering*

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## design chain

*David Twigg*

Design chains are a specific form of inter organ izational arrangement supporting product design and development activities. Whereas the management of "traditional" supply chains focuses on the production and distribution of physical goods, design chain management seeks primarily to influence those skilled participants, both internal and external to a focal firm, who contribute the capabilities (knowledge and ex pertise) necessary for the design and develop ment of a product: from initial concept to prototype and beyond.

Many organizations "trade" in design: in the same way that product manufacturers rely upon material inputs, product design processes depend upon the accumulation and codification of information (i.e., customer requirements, ad vances in technology, manufacturing process knowledge, etc.). These inputs may be internal ized within the focal firm; indeed, "[p]reviously design had been conceived as an activity always undertaken within the vertically integrated en terprise as in the case of Ford" (Clark and Star key, 1988). However, it has always been common for firms to outsource design work to the rele vant experts (*see* OUTSOURCING) and act as a focal point for the coordination of the design process. Correspondingly, design chain manage ment involves making decisions to build/retain or buy in/outsource design capabilities in re sponse to a specific competitive environment. More generally, however, today's increased use of technology and advanced materials in prod ucts, and the strategic concentration on core capabilities, means that the identification and management of external design capabilities has grown in importance. In the case of complex products an extensive network of external sources of information may be necessary, which contribute knowledge and expertise to the design and development of the product.

Given the complexity of their products, it is not surprising to discover that automotive firms are amongst the most sophisticated design chain managers. The traditional nature of the manu facturer–supplier relationship was dominated by suppliers who supplied a finished component, often from engineering designs supplied by the vehicle manufacturer, or designed by the sup plier from specified requirements. Increasingly, suppliers are contributing to design and engineering work much earlier in the process (*see* CONCURRENT ENGINEERING), so that they are more than purely manufacturing sites. During the various stages of product develop ment several organizations may thus be in volved. At concept stage, design houses may contribute to the design; at the detailed engin eering stage, large multinational suppliers may contribute proprietary "black box" designed component systems; and, at the process engin eering stage, manufacturing knowledge will be necessary, often relying upon the expertise of toolmakers, equipment manufacturers, and raw materials suppliers. In aggregate terms, the in volvement of suppliers in engineering activities may account for more than half of the total procurement cost of engineering. In automotive engineering, for example, 10 percent of engin eering procurement costs is for supplier propri etary parts (e.g., off the shelf items, such as tires or batteries), 40 percent is for "black box" items (e.g., systems or modules designed and de veloped to customer specifications by primary suppliers), and the remaining 50 percent is designed and developed in house by vehicle manufacturers. What these figures do not dem onstrate, however, is the increasing "gray box" element where suppliers "sit alongside" a vehicle manufacturer and provide process know ledge for product design work. Similarly, these figures do not emphasize specialist design house contributions at concept stage. Such organiza tions provide design and development expertise as a professional service and may provide proto type parts even though they do not manufacture parts.

See also *guest engineering; make or buy; organiza tion of development; product platforms; simultan eous development; time to market*

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### design for manufacture

*Michael Lewis*

Design for manufacture (DFM) is a process whereby the performance of a manufacturing system is formally included as a variable in de termining the effectiveness of the design of a product. The interest in DFM is based on con siderable empirical evidence that failure to con sider production requirements at the design stage can lead to products which are either of poor quality or high cost, or both. Without proper consideration of manufacturing process constraints and opportunities during design, fea tures may be incorporated which either fall out side the range of economically or technically feasible manufacture or, less obviously, fail to capitalize upon the capabilities of PROCESS TECHNOLOGY which may themselves suggest design changes. Attempting to rectify such fail ures later in the design process usually involves inconvenience and extra cost.

DFM is a general term that includes more specific examples of the relationship between design and manufacturing processes: design for fabrication (DFF) deals with metal forming, shaping, or jointing processes; design for assem bly (DFA) deals with assembly processes, and so on. Although DFM does not necessarily imply any concurrent development of product and process, its underlying systems philosophy is strongly related to concepts such as SIMUL TANEOUS DEVELOPMENT and VALUE EN GINEERING.

The success of design efforts using DFM principles can be quantified using one of several techniques, the best known of which is the Boothroyd–Dewhurst method. A more general benefit of such methods is that they formalize and codify DFM and in doing so reinforce its principles as good design practice. Similar benefits are ascribed to the computer aided DFM packages used to assist designers (*see* COMPUTER AIDED DESIGN).

See also *design; design chain; design–manufactur ing interface; quality function deployment; Taguchi methods; time to market*

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### design manufacturing interface

*Chris Voss*

One of the negative impacts of functional or ganization structures (sometimes pejoratively labeled "silos") is that technical design/

engineering expertise is separated from production/manufacturing expertise to the competitive detriment of the firm: the sustainable operational capability to win orders and gain competitive advantage does not come from the manufacturing function alone, it is part of a wider set of interlinked functions. More specifically, the complexity of manufacturing and product technologies suggests that the engineering function should have a manufacturing input during the design process, and likewise manufacturing requires engineering input during the early stages of product ramp up and production. A key managerial concern for many functionally structured companies therefore is the mechanism they choose to help integrate or couple the product engineering and manufacturing functions. High degrees of coupling between engineering and manufacturing is particularly essential when the market based priorities include fast product development times.

Integration between functions can be seen as a supply chain dedicated to internal problem solving: the greater the complexity and urgency of the problem, the greater the need for and intensity of information flows. One way of characterizing the nature of the information flows is to consider the customer specificity of any given order. Where orders are placed in manufacturing, such as in make to stock and make to order environments, products are developed prior to being sold to customers. Transfer of new products to manufacture in this context should be a controlled and discrete process. Where orders are placed on engineering, such as design or concept to order, the development process begins in the customer and continues through to manufacturing, sometimes as a continuous process. A hybrid between these is where products are tailored to customer preferences; in high volume products this is often known as mass customization. Here the integration between product engineering and manufacture is intense, requiring sophisticated systems of design and communication. This integration may also extend to the customer (*see* BUILD TO ORDER). Specific design–manufacturing integration mechanisms might include the use of temporary cross functional teams or more permanent information management – the use of common databases can facilitate rapid transfer of information and problem solving. They also enable projects to be managed with a wide geographical spread, leading to "virtual" project organizations.

See also *computer aided design; concurrent engineering; design for manufacture; project leadership; simultaneous development*

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## division of labor

*David Bennett*

Division of labor means dividing a total task down into smaller parts, each of which is accomplished by a single person. It is an idea that has been evident in job design from the earliest times of organizational activity (arguably back to Greece in the fourth century BCE), though it was first formalized as a concept by the economist Adam Smith in his *Wealth of Nations* in 1746.

Smith said labor should be divided because the process of division made tasks simpler, easier to learn, and enabled them to be more quickly carried out. Through the division of labor the output of a given number of people in a given time could be greatly increased.

One of the most dramatic demonstrations of the division of labor principle was provided by Eli Whitney who, during the American War of Independence, fulfilled a government contract to supply muskets to the army by coupling the principle with the idea of parts standardization. This represented a radical departure from estab lished practice for arms production, where every item was crafted and individual products were unique.

Today the division of labor principle is still popular, particularly in batch and line processes manufacturing where tasks are carried out repeatedly on batches of products or continu ously on a line. The continuing popularity of the idea is because, in spite of its drawbacks, there are some advantages in division of labor principles.

- *It promotes faster learning.* It is easier to learn how to do a relatively short and simple task than a long and complex one.
- *Automation becomes easier.* Dividing a total task into small parts raises the possibility of automating some of those small tasks.
- *Reduced non productive work.* This is prob ably the most important benefit of division of labor and goes some way to explaining why highly divided jobs still exist. In large, com plex tasks the proportion of time spent picking up tools and materials, putting them down again, and finding, positioning, and searching can be relatively high. None of these "non productive" activities contrib utes directly to making the product; they are there because of the way the job has been designed. When jobs are short and repetitive, individual operatives are concen trating only on one piece of the job. Specialist equipment and materials handling devices can be devised to help them carry out their job more efficiently and non productive work can be considerably reduced.

All these benefits contributed to the wide adop tion of division of labor principles as industrial ization took hold in the developed economies of the early twentieth century. Henry Ford de scribed his use of the principles for the manu facture of the flywheel magneto of the "Model T" in 1913.

> We had previously assembled the flywheel magneto in the usual method. With one workman doing a complete job he could turn out from thirty-five to forty pieces in a nine hour day, or about twenty minutes to an assembly. What he did alone was then spread into twenty-nine operations; that cut down the assembly time to thirteen minutes ten seconds. Then we raised the height of the line eight inches this was in 1914 and cut the time to seven minutes. Further experimenting with the speed that the work should move at cut the time down to five minutes. In short, the result is this; by aid of scientific study one man is now able to do somewhat more than four did only a comparatively few years ago. That line established the efficiency of the method and we now use it everywhere. (Ford, 1924)

However, there are also serious drawbacks to highly divided jobs.

- *Monotony.* The shorter the task, the more often operators will need to repeat the task. As well as any ethical objections to deliber ately designing monotonous jobs, there are other objections to jobs that induce such boredom that the likelihood of absenteeism, staff turnover, error, and sabotage is in creased.
- *Physical injury.* The continued repetition of a very narrow range of movements, as well as being monotonous, in extreme cases leads to physical injury. This is sometimes called repetitive strain injury (RSI).
- *Low flexibility.* Dividing a task up into many small parts often gives the job design a rigid ity that is difficult to change. Small product changes may mean changing every oper ator's set of tasks, which can be a long and difficult procedure.
- *Poor robustness.* Highly divided jobs imply materials passing between several stages. If one of these stages fails, the whole operation is affected.

See also *empowerment; group working; job design; job enlargement; job enrichment; job rotation; method study; teleworking; work organization*

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## DMAIC cycle

*Alan Betts*

The DMAIC cycle is an integral part of the SIX SIGMA improvement approach. It starts with defining the problem or problems, partly to understand the scope of what needs to be done and partly to define exactly the requirements of the process improvement. Often at this stage a formal goal or target for the improvement is set. After definition comes the measurement stage. This is an important point in the cycle, and in the Six Sigma approach generally, which em phasizes the importance of working with hard evidence rather than opinion. This stage in volves validating the problem to make sure that it really is a problem worth solving, using data to refine the problem, and measuring exactly what is happening. Once these measurements have been established, they can be analyzed. The an alysis stage is sometimes seen as an opportunity to develop hypotheses as to what the root causes of the problem really are. Such hypotheses are validated (or not) by the analysis and the main root causes of the problem identified. Once the causes of the problem are identified, work can begin on improving the process. Ideas are de veloped to remove the root causes of problems, solutions are tested, and those solutions that seem to work are implemented, formalized, and results measured. The improved process needs then to be continually monitored and controlled to check that the improved level of performance is sustaining. After this point the cycle starts again and defines the problems that are prevent ing further improvement.

It is the last point about both cycles that is the most important – the cycle starts again. It is only by accepting that in a CONTINUOUS IM PROVEMENT philosophy these cycles quite lit erally never stop that improvement becomes part of every person's job.

See also *PDCA cycle*

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## double-loop learning

*Michael Lewis*

In seeking to understand how to maximize or ganizational potential, scholars have identified a number of models of aggregate "learning": ar guably, one of the most relevant to operations management (OM) is the model of single and double loop learning developed by Argyris and Schon (1978).

### Double-Loop Learning (DLL)

If single loop learning is essentially operational learning that does not question underlying values and norms, then DLL can be understood by thinking about the sort of strategic organiza tional inquiries that seek to resolve structural incompatibility between resource and require ment profiles, that question fundamental service or market positions, or even the underlying cul ture of the operation. This kind of learning im plies an ability to challenge existing operating assumptions in a fundamental way, seeking to reframe competitive questions and remain open to all sorts of contextual changes in the environ ment. This is of course very difficult to achieve in practice, especially as most operations tend to reward experience and past achievement (rather than potential) at both an individual and group level.

### Downsides?

It is also clear that DLL can have dysfunctional effects. Questioning norms and values, encour aging dissent from established ways of working, or simply spending too much time "thinking instead of doing" (because DLL is an essentially cognitive process compared with the very prac tical basis of single loop) can create instability. It can engender a low trust environment or en courage defensive behavior. It can generate cre ativity of the wrong kind, as people devote their time and energy to playing games and avoiding or bypassing certain issues. In an organization with high levels of staff turnover and where individual staff members have less direct market value (i.e., an advertising executive has a port folio of work and, more importantly, client rela tionships), the creation of trust and open communication environments cannot be taken for granted. Moreover, even in a small know ledge creating operation like an advertising agency, too much double loop learning can create instability as a consequence of overreac tions and over analysis. The operation can become prone to the exaggeration of small errors and overly responsive to fads and fashions. If an operation (like an individual) is very sensitive to its environment and at the same time prone to introspection, it can become very difficult to distinguish noise from real issues.

### Balancing Single- and Double-Loop Learning

An operation needs both limited search learning in order to develop specific capabilities and op portunities for more expanded search. Argyris and Schon, the originators of the terminology, argued that organizations need single loop to create consistency and stability and, at the same time, because organizational design is an in accurate and imperfect process, continual reflec tion upon the internal and external context is also necessary. This can be achieved in a variety of ways. Simplistically, over time the operation can have distinct phases where it emphasizes single or double loop learning or if it is large enough it can prioritize different search activ ities in different parts of the organization at different times.

See also *high involvement innovation; innovator's dilemma; single loop learning*

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## dynamic capabilities

*Michael Lewis*

For the most part, terms like resource, compe tence, and capability (together with various common qualifiers like strategic, dynamic, key, etc.) are used interchangeably. However, there is a specific definitional form for the notion of dynamic capability that justifies its inclusion as a separate entry. Resource based competence can provide a robust defense against competitive attack and protect existing competitive advan tages, but any approach exclusively based around defensive barriers to imitation offers only a static view of a company's OPERATIONS STRATEGY. Any assessment of *sustainable* com petitive advantage should include barriers to imitation but also explore the dynamic efforts a firm makes to improve what it currently does well on a continuous basis and how it intends to innovate for the future. The underlying mech anisms that allow a firm to build up advantage from the way it changes what it "has" and what it "does" are called *dynamic capabilities* (Teece and Pisano, 1994; Teece, Pisano, and Shuen, 1997).

Dynamic capabilities will be built up from the firm's resources and processes, and be mediated by external market influences. Crucially, how ever, dynamic capabilities will also be defined in large part by how managers make judgments about the firm and its future.

See also *competence; double loop learning; innovator's dilemma; single loop learning*

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# E

**e-business**

*Eamon Ambrose*

Electronic business (e business) is the conduct of business on the Internet, including buying, selling, servicing customers, and collaborating with business partners. One of the first popular uses of the term was by IBM. In 1997, it launched a promotion campaign centered around the term. With the arrival of the Internet and the worldwide web (WWW), there has been enormous interest in the subject of e commerce in recent times. However, the phenomenon of electronic communication for business purposes has been with us since the advent of the tele phone. According to MIT, e business can be defined as the practice of using information technologies to increase revenues and cut costs. This can include technologies such as the tele phone and fax, electronic data interchange (EDI), wide area networks (WANs), and the Internet. While the impact of the Internet is certainly wide ranging, many of the issues in volved have been around for a while. A general trend can be seen over the last 20 years whereby communication technologies have progressively changed the manner in which interaction be tween individuals and organizations takes place.

Electronic commerce has already existed for over 20 years, involving a variety of information technologies. EDI is considered to be a widely used technology for e commerce between busi nesses, yet it is used by less than 1 percent of companies in Europe and the US. While Inter net and email usage is growing both in business and by consumers, the amount and value of transactions carried out using e commerce remain relatively low. The latest innovations in e commerce technology are based on mobile wireless technologies, which are still very expen sive and are showing limited market penetration. Hence, much electronic commerce is still trans acted using the telephone and fax machine, des pite the availability of newer technologies.

Understanding e business necessitates look ing at the way in which IT creates value in a commercial environment. The sources of value creation cited in the e commerce literature in clude a number of core elements that are sources of value for buyers and suppliers. These elem ents encapsulate the value generated by using e commerce as opposed to a traditional procure ment processes.

- Data accuracy is greatly increased, through central information storage and reduced manual translation and inputting.
- Capture of data is automatic and the cost of retrieval is virtually zero. Data are stored in a format suited to easy analysis and manipula tion.
- Communication speeds are greatly increased with electronic data. Communications over distance are not costly or even a cause of time delay.
- Integration of electronic systems, either within or between organizations, allows for greater transparency of information.
- The Internet provides a level of reach and connectivity never before available.
- The richness of data transfer possible via the Internet is greater with the range of formats available such as HTML, audio, and video.

These basic elements can be combined to gener ate the value streams identified in the literature such as lower transactions costs and improved control of maverick buying. For example, mav erick purchasing by a group of decentralized buyers can be controlled through the use of integrated systems for purchasing requests, approvals, and invoicing, leveraging the data capture and accuracy inherent in the electronic medium.

E commerce is often divided into two distinct categories depending on the parties involved in the interaction.

- Business to consumer (B2C) refers to the interactions between businesses and end consumers, involving the exchange of goods and services and related communications. Companies such as Amazon and Dell have built significant B2C businesses through their web enabled operations.
- Business to business (B2B) refers to the ac tivities further up the supply chain, where businesses exchange goods and services re quired as part of their internal operations, either directly as raw materials or indirectly as outsourced operational supplies. B2B op erations are often characterized as vertical, where businesses in one industry interact electronically, or horizontal, where indirect supplies are offered across a range of indus tries. This category includes government/ business activity also.

A third category is peer to peer (P2P) activity taking place between individuals, sometimes with an intermediary acting as a facilitator. The P2P market is seen as the future development as access becomes cheaper and technology such as wireless broadband allows for mobile personal activity.

Where goods or services traded are informa tion based, e commerce represents a particularly significant development. In particular the Inter net has allowed a number of developments to evolve at a much faster rate.

- Disintermediation, where brokers, retailers, and distributors are no longer required in the supply chain.
- Mass customization, where the product offering can be cheaply modified based on customer preferences.
- Information mining, the ability to build up customer profiles through the enhanced data capture, leading to more focused offerings and greatly enhanced customer relationship management (CRM).
- Global reach and 24 hour availability – the Internet allows information businesses to be open all hours and accessible from anywhere in the world, irrespective of time zones.
- Multimedia interactivity – the ability to transmit data, audio, and video has greatly enhanced e commerce communication, as has the ability to interact in real time.
- Network effects – as more people connect to the Internet, the value of the Internet to those already connected increases.

Disintermediation is particularly visible in in dustries such as air travel and financial markets. Travel agents are struggling to add value to a process where customers can source and pur chase air travel without a ticket even having to be printed. Share dealing has also been revolu tionized by the access to online brokers. The music industry is seeing a radical change where customers will eventually be able to pick and choose exactly what music to buy, without being restricted to prearranged compilations. In many industries, the information gained about consumers' shopping habits has a value in itself, both to the selling company as a forecasting tool and to sellers of complementary goods and services.

## E-business: Procurement

The complete procurement function can be broken down into the typical process steps – sourcing of goods and services, discovery and comparison of prices, negotiation, purchase agreement, payment, delivery, and after sales service.

Sourcing of goods and services is greatly en hanced by the Internet, especially where the product is easily defined electronically, i.e., where smell, touch, or physical interaction with the product is not required. Consumer items such as books, computer hardware, and some groceries are good examples of this, while fresh fruit and fashion clothing will still tend to be bought in the physical world. In general, B2B purchases are better suited to electronic sourcing as there is a greater tendency to specify the characteristics, allowing for a full description electronically. This results in reduced search costs, often in addition to lower purchase prices.

As with sourcing, price discovery and com parison is becoming increasingly sophisticated, particularly for routine purchases. Electronic markets bring together buyers and suppliers of commodities with a view to generating complete transparency, approaching the classical defin ition of an ideal market (see E INTERMEDIAR IES).

Where the process involves price (or specifi cation) negotiation, there tends to be preference for personal interaction. However, indications are that electronic auctions are generating sig nificant savings. In addition to the traditional auction format, the reverse e auction model is where a buyer offers a contract to supply goods and services, and suppliers bid to fulfill the contract at the lowest price.

The administration of the purchase agree ment is greatly simplified in e commerce, with requisitions, purchase orders, and expediting documents all generated and communicated electronically. Workflow systems can signifi cantly reduce transactions costs through stream lined purchasing processes.

One area where these benefits prove valuable is in the purchase of indirect supplies for a business, also known as maintenance repairs and operating (MRO) supplies – stationery, equipment spares, and facilities management. The products and services tend to be standard ized commodities, and they can be accurately specified electronically. Prices and product range can be compared easily and speedily. On the other hand, the value of the purchases can be relatively low, particularly where unplanned purchases have to be made due to equipment breakdown or stock shortages. Here the low transaction cost of e business generates signifi cant savings on the high number of low value purchases. Hence MRO supplies have been a fruitful area for e business, even before the Internet. Stationery and engineering supplies catalogues have been around for decades, allowing standard pricing and remote ordering.

### E-BUSINESS: SUPPLY CHAIN MANAGEMENT (SCM)

The key to effective SUPPLY CHAIN MANAGE MENT is well managed information flows. E commerce has in the past facilitated more effective and efficient information flows through the integration of enterprise resource planning (ERP) systems (*see* ENTERPRISE RE SOURCES PLANNING), the development of global LOGISTICS providers, and the speed of electronic communication. The Internet serves only to continue this facilitation at an ever in creasing rate.

Where previously integration between organ izations required significant capital investment and dedicated systems, this can now be achieved with less capital and with open standard systems. Hence communication between organizations can be achieved without the same requirement of a long term commitment. This has facilitated the move toward increased OUTSOURCING, as the dispersed supply chain can still be competi tive through the use of improved information management. Where previously a high level of communication would occur only between hier archical levels of a vertically integrated organiza tion, it is increasingly taking place between distinct organizations. These virtual hierarchies share sensitive information in a secure network among selected supply chain partners. The in formation can extend beyond sales forecasts and production plans to include joint product devel opment and collaboration.

See also *purchasing; supply network information systems*

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## economic order quantity

*John Mapes*

When placing an order for materials with a sup plier, the economic order quantity (EOQ) is the quantity for which the sum of total annual ordering and stockholding costs will be a minimum. If a large order is placed, then orders need to be placed less frequently so that annual ordering costs are less. On the other hand, the material ordered must be stored until it is required and so the larger the order, the larger the stockholding costs. The relationship between total annual costs and order quantity is shown graphically in figure 1. The most convenient way of calculating the EOQ is to use the formula shown below:

$$Q = \sqrt{\frac{2SD}{IV}}$$

where $Q$ is the economic order quantity in units, $S$ is the cost of raising a single order, $D$ is the annual demand in units, $I$ is the annual stockholding fraction (annual stockholding cost expressed as a fraction of average stock value), and $V$ is the value of one unit of stock.

Although the EOQ formula is a useful starting point for setting order quantities, it does have a number of limitations.

### Limitations of the EOQ Formula

1. The ordering cost, $S$, and the stockholding fraction, $I$, are very difficult to estimate accurately. Fortunately, the total cost curve is fairly flat for values of $Q$ near to the EOQ. Consequently, small errors in $S$ and $I$ have little effect on total costs.
2. Mechanical application of the formula may generate order quantities for some items representing several years' usage. This is normally dealt with by setting an upper limit on the order quantity.
3. Unit value is assumed to be constant and unaffected by order quantity so that no account is taken of bulk discounts. This is a fairly major omission as the size of the bulk discount may be far in excess of any of the costs considered earlier. However, methods of allowing for bulk discounts in calculating the EOQ are available.
4. Rigorous application of the formula to every single stock item may require an unacceptable change in the size of the purchasing department or in the amount of storage space needed. Bearing in mind the uncertainties about the values of $S$ and $I$, one can understand managers being a little nervous of using the formula if its use will require the construction of two additional warehouses or the laying off of half the staff in the purchasing department.
5. Manufacturing decisions on batch size have more to do with balancing capacity than bal

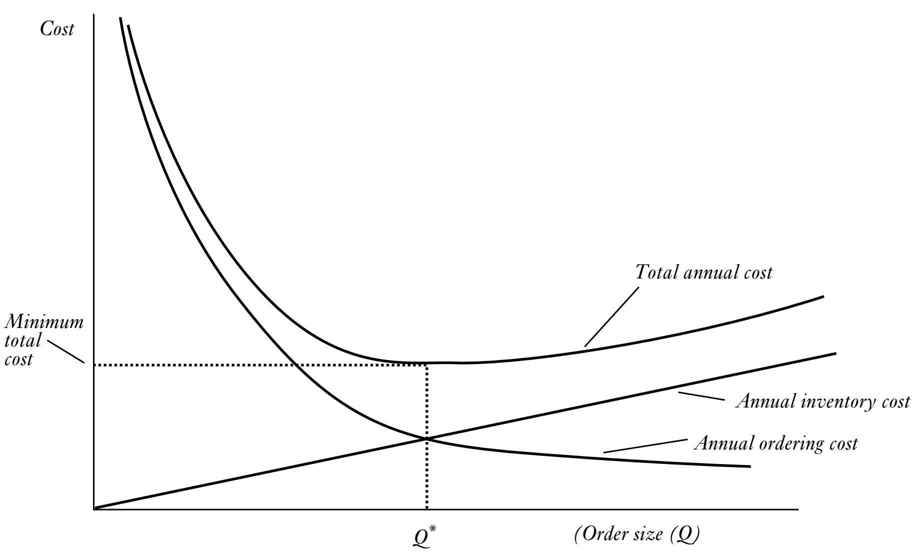


**Figure 1** Variation of total annual cost with order size

ancing setup and stockholding costs. When demand is less than capacity, then any re duction in the number of setups just in creases idle time. The effect of this on total costs will be minimal. It therefore makes sense to reduce batch sizes until setup times plus run times equal time available, perhaps leaving a small amount of spare capacity in case of unplanned lost time.

See also *inventory management; just in time; lot sizing in MRP; materials management; setup re duction*

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## e-intermediaries

*Eamon Ambrose*

An e intermediary is any organization that facili tates business buyers and business sellers com municating in order to trade goods or services, using the Internet as the communication chan nel. It is a topic that has attracted much interest within the field of business to business (B2B) e commerce. Over the Internet, much of the B2B e commerce involves intermediaries providing services to assist both buyers and suppliers. In the literature these are variously referred to as e marketplaces, e hubs, market sites, or ex changes.

In the various strands of literature, a distinc tion has regularly been made between electronic markets and electronic hierarchies. Markets are open fora, where buyers and suppliers can inter act, with a traditional arm's length relationship. Simple price generating mechanisms result in a one off transaction, usually with a short time horizon. Market functions include matching of buyers and sellers, facilitation of the transaction, and provision of market infrastructure. Hier archies are private fora where selected buyers and suppliers interact in complex transactions, with obligational contractual relationships. These can be inter or intra organizational rela tionships, depending on the governance struc ture. Electronic hierarchy activity includes joint problem solving, forecasting, product develop ment, and collaboration.

Where e commerce is aimed at reducing ad ministrative costs by removing process ineffi ciencies in the traditional manual systems, it tends to be most effective when creating markets for commodity products with simple procure ment processes, such as maintenance repairs and operating (MRO) items. Portals that facilitate collaborative activities and information sharing tend to deal with more complex products and processes, such as distributed product develop ment. A range of models has been proposed to classify the different e commerce intermediaries currently operating, the most common being the Kaplan and Sawnhey (2000) matrix, which con siders the type of goods and services being purchased and the characteristics of the pur chase. The goods can be direct manufacturing materials or indirect operating supplies. The purchase can involve a short term spot sourcing mechanism, or a more long term systematic sourcing.

Intermediaries usually offer a range of func tionality, which can be used selectively, includ ing sourcing, price comparison, tendering, auctions, purchasing, payment, and LOGIS TICS. There is a general trend toward additional *added value services* in order to move beyond simple transaction cost reduction. These include membership of a community sharing informa tion, integration to the participants' own enter prise resource planning (ERP) systems (*see* ENTERPRISE RESOURCES PLANNING), and facilitation of complex transactions.

See also *e business; purchasing; supply chain management; supply network information sys tems*

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**empowerment**

*John Heap*

Empowerment is an extension of the autonomy job characteristic prominent in the behavioral approach to job design. However, it is usually taken to mean more than autonomy. Whereas autonomy means giving staff the ability to change how they do their jobs, empowerment means giving staff the authority to make changes to the job itself, as well as how it is performed. This can be designed into jobs to different degrees – "suggestion involvement," "job involvement," or "high involvement" (Bowen and Lawler, 1992a, b).

- *Suggestion involvement* is not really empowerment in its true form but does "empower" staff to contribute their suggestions for how the operation might be improved. However, staff do not have the autonomy to implement changes to their jobs. High volume operations, such as fast food restaurants, may choose not to dilute their highly standardized task methods, yet they do want staff to be involved in how these methods are implemented.
- *Job involvement* goes much further and empowers staff to redesign their jobs. However, again there must be some limits to the way each individual makes changes that could impact on other staff and on the performance of the operations as a whole.
- *High involvement* implies including all staff in the strategic direction and performance of the whole organization. This is the most radical type of empowerment with relatively few examples. However, the degree to which individual staff of an operation contribute toward, and take responsibility for, overall strategy can be seen as a variable of job design. For example, a professional service firm might move in this direction, partly to motivate all its staff, partly to insure that the operation can capture potentially useful ideas.

The *benefits* of empowerment are generally seen as including the following:

- faster online responses to customer needs;
- faster online responses to dissatisfied customers;
- employees feel better about their jobs;
- employees will interact with customers with more enthusiasm;
- empowered employees can be a useful source of service;
- it promotes "word of mouth" advertising and customer retention.

However, there are *costs* associated with empowerment:

**Table 1** The contingencies of empowerment

| *Factor* | *Non empowerment approach* | *Empowerment approach* |
|---|---|---|
| Basic business strategy | Low cost, high volume, personalized | Differentiation, customized |
| Links with customer | Transaction, short time period | Relationship, long time period |
| Technology | Routine, simple | Non routine, complex |
| Business environment | Predictable, few surprises | Unpredictable, many surprises |
| Types of people | Autocratic managers, employees with low growth needs, low social needs, and weak interpersonal skills | Democratic managers, employees with high growth needs, high social needs, and strong interpersonal skills |

*Source*: Adapted from Bowen and Lawler (1992a).

- larger selection and training costs;
- slower or inconsistent training;
- violation of equity of service and perceived fair play;
- "give aways" and bad decisions made by employees.

A number of key factors will determine whether the benefits outweigh the costs of empowerment. These factors are contained in table 1. The closer an individual job design requirement is to the right of the continuum, the more likely it is that an empowerment approach should be adopted.

See also *division of labor; group working; job design; job enlargement; job enrichment; job rotation; method study; teleworking; work organization*

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## enterprise project management

*Harvey Maylor*

Enterprise project management (or computer assisted project management) systems are computer based systems that integrate a number of project management functions. Since the emergence of computer based modeling, increasingly sophisticated software for project planning and control has been commercially developed. The rather tedious computation necessary in network planning can relatively easily be performed by project planning models. The speed of computation allows for frequent updates to project plans. Similarly, if updated information is both accurate and frequent, such computer based systems can also provide effective project control data. Enterprise project management (EPM) systems combine these established functions with the potential for using computer based project management systems for communication within large and complex projects.

Project management functions often found integrated within EPM systems include the following:

- project planning
- resource scheduling
- project control
- project modeling
- project portfolio analysis
- communication tools

Project planning involves critical path analysis and scheduling, an understanding of float, and the sending of instructions on when to start activities. Resource scheduling looks at the resource implications of planning decisions and the way a project may have to be changed to accommodate resource constraints. Project control includes simple budgeting and cost management together with more sophisticated earned value control. However, EPM also includes other elements. Project modeling involves the use of project planning methods to explore alternative approaches to a project, identifying where failure might occur and exploring the changes to the project that may have to be made under alternative future scenarios. Project portfolio analysis acknowledges that, for many organizations, several projects have to be managed simultaneously. Usually these share common resources. Therefore, not only will delays in one activity within a project affect other activities in that project, they may also have an impact on completely different projects that are relying on the same resource. Finally, integrated EPM systems can help to communicate, both within a project and to outside organizations that may be contributing to the project. Much of this communication facility is web based. Project portals can allow all stakeholders to transact activities and gain a clear view of the current status of a project. Automatic notification of significant milestones can be made by email. At a very basic level, the various documents that specify parts of the project can be stored in an online library. Some argue that it is this last element of communication capabilities that is the most useful part of EPM systems.

See also *program management; project control; project cost management and control; project man agement; project risk management; project stake holders*

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## enterprise resources planning

*Henrique Correa*

Enterprise resource planning systems are com puter systems that link application software in sales, order management, manufacturing, finance, accounting, human resources, distribu tion, and other functions in a firm into a tightly integrated single system with shared data and visibility across the business. More generally, enterprise resources planning (ERP) is a method for the effective planning and control of all re sources needed to take, make, ship, and account for customer orders in a manufacturing, distri bution, or service environment. The term was coined by the Gartner Group in the early 1990s as an evolution of and an extension to manufac turing resource planning (MRPII) systems (Mabert, Soni, and Venkataramanan, 2001). The potential benefits of ERP systems, when properly selected and implemented, are instant access to timely information for better visibility of operational information, and support for inte grated operational decision making, allowing companies to use their resources better in their efforts to reconcile supply and demand. How ever, these systems are considered to be expen sive and complex, and implementing one can be a difficult, time consuming, and costly project for a company.

### From MRP to MRPII to ERP

Today's ERP systems have evolved from the early operations management (OM) computer applications of the 1950s and 1960s: BILL OF MATERIAL (BOM) processors. These programs were initially used for storing, maintaining, and retrieving product bill of material information, but as computing power grew they developed into the first "material requirements planning" (MRP) systems. MRP became an important decision support tool for the management of materials; however, it was not long before deci sion makers started to request decision support tools that considered not only materials planning but also machine and labor capacity planning. In response, software developers started to add modules to the original MRP solution to support capacity planning, shop floor control, master production scheduling (MPS) etc. The new, broader systems were renamed MRPII, with the acronym now referring to manufacturing resources planning. Subsequently, some soft ware vendors began to offer sales and operations management (SandOP) modules for MRPII, designed to support long term decisions related to operations planning and control. Interest ingly, despite the powerful functionality avail able, many firms claimed that MRPII was not delivering the promised benefits and it became clear that such systems were not a panacea. The 1990s brought even more IT developments – increasingly including communication and networking technologies – and with them the possibility of integrating the MRPII with other corporate systems (administrative and financial, fiscal, accounting, human resources, etc.). A new class of suppliers emerged with these expanded solutions: SAP, BAAN, ORACLE, QAD, SSA, and so on. The solution that they offered could no longer be called MRPII, since its scope had expanded to cover almost all areas of the enter prise. As a result, the new systems became known as ERP systems.

### The General Functionality of ERP

ERP is seen as having the potential to very significantly improve the performance of many companies in many different sectors. This is partly because of the greatly enhanced visibility that information integration gives, but it is also a function of the discipline that ERP demands. Yet this discipline is itself a "double edged" sword. On one hand, it "sharpens up" the man agement of every process within an organization, allowing BEST PRACTICE (or at least common practice) to be implemented uniformly through the business. No longer will individual idiosyncratic behavior by one part of a company's operations cause disruption to all other processes. On the other hand, it is the rigidity of this discipline that is both difficult to achieve and (arguably) inappropriate for all parts of the business. Nevertheless, the generally accepted benefits of ERP are held to be the following.

- Because software communicates across all functions, there is absolute visibility of what is happening in all parts of the business.
- The discipline of forcing business process based changes is an effective mechanism for making all parts of the business more efficient.
- There is better "sense of control" of operations that will form the basis for CONTINUOUS IMPROVEMENT (albeit within the confines of the common process structures).
- It enables far more sophisticated communication with customers, suppliers, and other business partners, often giving more accurate and timely information.
- It is capable of integrating whole supply chains including suppliers' suppliers and customers' customers.

In fact, although the integration of several databases lies at the heart of ERP's power, it is nonetheless difficult to achieve in practice. This is why ERP installation can be particularly expensive. Attempting to get new systems and databases to talk to old (sometimes called *legacy*) systems can be very problematic. Not surprisingly, many companies choose to replace most, if not all, their existing systems simultaneously. New common systems and relational databases help to insure the smooth transfer of data between different parts of the organization.

In addition to the integration of systems, ERP usually includes other features that make it a powerful planning and control tool:

- It can be based on a client/server architecture; i.e., access to the information systems is open to anyone whose computer is linked to central computers.
- It can include decision support facilities that enable operations decision makers to include the latest company information.
- It is often linked to external extranet systems, such as the electronic data interchange (EDI) systems, which are linked to the company's supply chain partners.
- It can be interfaced with standard applications programs that are commonly used by most managers, such as spreadsheets.
- Often, ERP systems are able to operate on most common platforms, such as Windows NT or UNIX, or Linux.

### Critical Perspectives

Far from being the magic ingredient that allows operations to fully integrate all their information, ERP is regarded by some as one of the most expensive ways of getting zero or even negative return on investment. For example, the American chemicals giant Dow Chemical spent almost half a billion dollars and seven years implementing an ERP system which became outdated almost as soon as it was implemented. One company, FoxMeyer Drug, claimed that the expense and problems it encountered in implementing ERP eventually drove it into bankruptcy. One problem is that ERP implementation is expensive. This is partly because of the need to customize the system, understand its implications for the organization, and train staff to use it. Spending on what some call the *ERP ecosystem* (consulting, hardware, networking, and complementary applications) has been estimated as being twice the spending on the software itself. But it is not only the expense that has disillusioned many companies, it is also the returns they have had for their investment. Some studies show that the vast majority of companies implementing ERP are disappointed with the effect it has had on their businesses. Certainly, many companies find that they have to (sometimes fundamentally) change the way they organize their operations in order to fit in with ERP systems. This organizational impact of ERP (which has been described as the corporate equivalent of root canal work) can have a significantly disruptive effect on the organization's operations.

See also *e business; manufacturing resources planning; master production schedule; material requirements planning; planning and control in operations*

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## ergonomics

*John Heap*

Ergonomics is the study of how the human body reacts to its immediate workplace and environment. Ergonomics may also be termed "human factors engineering" or just "human factors." It is concerned primarily with the physiological aspects of JOB DESIGN and WORK ORGANIZATION in two areas. The first is concerned with how people relate to the physical aspects of their workplace such as machines, seats, desks, etc. The second is concerned with how people relate to the environmental conditions of their immediate work area such as temperature, lighting, noise, etc.

Both aspects of ergonomics have two common characteristics. First, there is the implicit assumption that there must be a fit between people and the jobs they do, and second, that making job design decisions must be on a basis of data collection and experimentation. Data on how people react to their workplace or immediate environment should be collected on a probabilistic basis which allows for the naturally occurring variation in individual reactions.

### Ergonomic Workplace Design

The design and layout of a workplace depends on the nature of work being undertaken, and its sequencing, and this in turn depends on the process of which the work is a part. The design must include the spatial arrangements of the various components of the work process, such as equipment, tools, and furniture. Key factors are the degree of variability in the tasks undertaken in the workplace, and the degree to which one workstation is decoupled from others in the same workplace. Variability affects the level of prescription of the layout and may affect the range of fixtures, fittings, tools, and equipment that must be accommodated within the workplace. Decoupling affects the degree of temporary storage of incoming and outgoing materials that must be provided – in a highly coupled environment, no such storage is necessary since the work flows through the workplace without delay from one workstation to the next (*see* PRODUCT LAYOUT).

The aim of the design of workplaces and individual workstations is to provide for effective and efficient working which can allow for the defined flexibility of the manufacturing process and for differences in operator characteristics (height, reach, etc.) and for differences in their preferred working positions (standing, seated). This increases the flexibility of the workplace and reduces the fatigue induced by a constant body position. The PRINCIPLES OF MOTION ECONOMY provide a starting point for the ergonomic design of workstations and workplaces, but a more comprehensive, albeit basic, knowledge of anthropometry, and access to ANTHROPOMETRIC DATA, is required. A number of specific charts and diagrams have been developed to aid the recording and analysis of workplace and workstation layouts. These include process charts, charts that specifically record travel and movement, and those such as MULTIPLE ACTIVITY CHARTS designed to record the interrelationships over time between teams of workers or between workers and equipment. It is common to make use of plans and drawings that represent the work area and to experiment with layouts using templates and models. The aims are to insure first that movements within a process are minimized (both in number and in distance), and then that necessary movements take place by the most appropriate method. Once the schedule of movement is fixed, individual workstations can be placed on the layout and then designed as ergonomic stations.

Ergonomic Work Environment Design

The work environment is a generic term used to describe the sum of a variety of factors – principally temperature, ventilation, noise, illumination, vibration, and exposure to harmful substances. As a minimal position, organizations must comply with statutory legislation. The working environment is an important determinant of worker health, safety, and wellbeing, and as a result directly affects worker (and therefore organizational) performance. For all the factors, it is possible to establish a range of exposure intensity under which it is reasonable to expect a worker to give good performance without undue short or longer term ill effects. For some of the factors, especially temperature and illumination, the range is bounded by unsatisfactory intensity levels on either side – too much heat or light is as harmful as too little. Knowledge on acceptable exposure intensities changes as understanding of each factor improves, and as observation of actual results extends. Thus, the impact of exposure to noise on hearing loss is better understood with regard to the effects of intermittent as distinct from continuous noise levels. The situation is further complicated since the various factors interrelate, and measures taken to alleviate the effects of one factor may result in increased sensitivity to another. As an example, clothing designed to protect from radiation exposure will significantly affect the worker's ability to withstand exposure to heat. Although work environments are designed for "average workers," it is also important to be aware of, and make allowances for, variation in the sensitivities of different personnel.

The factors that make environmental conditions severe and/or harmful can be complex. In the case of vibration, for example, a worker is affected according to the intensity of the vibration, the frequency of vibration, the duration, the posture of the worker while exposed to the vibration, and the manner by which the vibration is transmitted. The nature of the work being undertaken will influence whether vibration has an immediate and/or significant effect on performance.

Where the environment is considered unsatisfactory in some way, it is essential to consider protection in the form of special clothing or apparatus. Where this is not possible, a work–rest regime that permits the worker to recover from the effects of the environment must be implemented. (Note that recovery from an unsatisfactory regime need not be spent in relaxation; it can be spent performing other work in a satisfactory, or even beneficial, environment.)

In work measurement, it is usual to make additions to job completion times to compensate for the effects of an adverse environment. Such additions are normally based on one of a set of published tables which may have some currency within a particular country or industry. However, the research that underpins the derivation of these tables is at best incomplete, and it is wise to consider them as empirical guides with no official status.

See also *layout; method study*

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## ethics in operations management

*Michael Lewis*

There have always been, often complex, "ethical" consequences associated with almost every sphere of operations management (OM) activity. Consider the following high profile examples:

- On December 2, 1984, the risks associated with capacity and facilities management became the subject of international debate when, after a faulty pipe washing operation, the Union Carbide pesticide plant in Bhopal, India, released quantities of poisonous gas into the atmosphere. Estimates of the number of fatalities range from 3,000 to 10,000. Significantly from an operations perspective, the plant had only ever operated at 50 percent capacity because of declining global demand. The resultant cost pressures prompted managers to cut back expenditure on a range of facilities management practices. More generally, capacity related decisions (scale, location, etc.) are particularly prone to the kind of "bad news" stories that can contribute to risks. Media (and other stake holder) interest is normally directly related to the same range of operational, economic, and political factors that directly inform capacity management decisions.

- On February 26, 1995, Barings Bank went into administration. Its organizational struc tures had allowed its Far East operations to exceed normal risk exposures (the basic supervision principle is that no bank should risk more than it can afford to lose). Al though there were many different factors contributing to the failure, official investi gations made clear that Barings had no notion of workforce risk – its culture was one of "business first and control second." After starting work in Singapore, "rogue trader" Nick Leeson (a back office manager with no previous trading experience) created the account (88888) that became the mech anism for transferring S$1.7 billion to cover his catastrophic trading positions. Addition ally, in a global operating structure, there are unavoidable difficulties associated with management conducted without regular face to face meetings, in different time zones, and often in multiple languages.
- In 1990 Perrier ordered a product recall as reports of benzene contamination emerged. To compound the problem, explanations of the source of the benzene differed: Perrier (US) reported it was an exclusively North American issue; Perrier (France) stated the source was a cleaning fluid used on the US bottling line; Perrier (UK) said it had no idea what was going on! Three days after the French announcement, it was established that the contamination had been caused by a failure to replace charcoal filters in the technology used to process source water. This failure proved to be a significant source of advantage for Perrier's rivals who rapidly gained much more market share.
- In the mid 1970s, Dow Corning (already infamous for its production of Agent Orange during the Vietnam War) rapidly developed a silicone based breast implant to be able to take advantage of a booming cosmetic sur gery market. By the 1980s anecdotal evi dence of health problems led to a series of legal actions, and by 1992 the Food and Drug Administration (FDA) blocked fur ther sales and the firm halted production. By late 1994, the firm still faced thousands of lawsuits that eventually cost $3.2 billion to settle. Although the firm manufactured almost 5,000 other products, in 1995 it was forced to file for bankruptcy reorganization.

Customers' welfare is directly affected by many OM activities. The most obvious effect is that their safety might be compromised. If a product is badly assembled, or if the equipment used in a service (such as a rail transport system) is not maintained, customers may come to harm. How ever, customer safety is influenced by more than this; it could also be affected by the degree to which an operation discloses the details of its activities, e.g., in the case of an airline admitting that it has received bomb threats, or the full disclosure of all the components or ingredients in a product (which may prevent allergic reac tions). At a less serious level, the ethical frame work of operations decisions can affect the equity and fairness with which customers are treated (e.g., whether a bank should or should not discriminate between different customers in order to give priority to those from whom they can make more profit).

Employees are exposed to the ethical frame work of the organization throughout their working lives. Organizations are generally accepted as having a duty to their staff to prevent their exposure to hazards at work. In addition to preventing catastrophic physical injuries, this also means that organizations must take into account the longer term threat to staff health from, say, repetitive strain injury (RSI) due to short cycle repetitive work motions: Brown (1996: 168), for instance, describes the case of a Boeing employee suffering from repetitive motion disorders stemming from a poorly designed operating environment, who was awarded $1.6 million in damages. A more subtle ethical duty is the organization's responsibility to avoid undue workplace stress, caused, for example, through not providing employees with the information that allows them to understand the rationale and consequences of operations decisions, or expecting staff to take decisions for which they are not equipped.

Suppliers are often the source of an ethical dilemma for the operation; for example, is it legitimate to put suppliers under pressure not to trade with other organizations? Should organ izations impose their own ethical standards on suppliers (in the case of not wishing to exploit workers in developing countries)? The transpar ency in relations that is increasingly expected from suppliers also poses ethical dilemmas. If suppliers are expected to be transparent in opening up their costing calculations, should customers be equally transparent?

The community in general also has ethical expectations. Most evidently, organizations have a direct impact on levels of environmental pollution in the community. All manufacturing processes have waste emissions of some sort, often governed by legislation, although organ izations often have some discretion over their responsibility to minimize their pollution caus ing activities on one hand, and the cost of doing this on the other. The ethical dilemma is similar for a company's products after sale. The extent to which an organization should insure that its products are easily disposed of, or recycled, or made sufficiently durable that they do not need replacing, has clear ethical implications.

In conclusion, day to day operations in vari ous types of manufacturing and service organiza tion have always required managers to cope with hazards for their employees, customers, the en vironment, and so on, but increasingly an emerging competitive, social, and political con text for many operations means that significant external scrutiny (in areas such as health and safety, JOB DESIGN, training, product/service design, SUPPLY CHAIN MANAGEMENT, etc.) has now rendered ethical factors a significant and growing part of the OM task.

See also *failure in operations; life cycle effects; operational anorexia; product–service systems; risk and operations*

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## extraprise

*Christer Karlsson*

An extraprise consists of the core company that is the central actor in its network, together with the other actors, other resources, and other ac tivities in the network. The extraprise, therefore, is a holistic perspective on resources that will be involved in different networks and look different at different times.

### Evolution of an Extraprise

Companies organize in a way that involves an increasing number of activities that are external to their traditional organizational boundaries. As a consequence, managing operations involves a number of issues and actions that deal with ex ternal organizations. The shift toward this larger perspective may be called a shift from an enter prise to an extraprise. External collaboration also includes other original equipment manufacturer (OEM) companies, including competitors. This type of collaboration concerns not only oper ational but also strategic issues, such as technical development. These networks may be based not only on ownership but also on more complex and varied types of integration such as licensing agreements and joint ventures of various kinds.

To be able to handle much more complex offerings, companies often abandon lower levels of technology and leave subsystems and com ponents to suppliers. Under such circumstances, in house activities may focus on system integra tion and product characteristics. Because best sources are sought, the probability will be high that many components and systems in a complex product are sourced externally. Such a best sourcing strategy pushes a shift in perspective on economy of scale from the plant level to the global industrial network level. Also, the special ist company with higher process competence and larger volumes may offer higher quality and better productivity. Similarly, the business relationship will often stress dependability and the flexibility that is offered through contractual relations replacing own investments.

### Extraprise Resources

Access to global manufacturing resources expands alternatives for purchasing and pro curement as a whole. There is a choice of best inputs from worldwide locations along the value chain. As an effect partners become integrated parts of the extraprise. In addition to productiv ity, another point is that a basis upon which operations systems will be designed is the need to be innovative and fast to market, as well as to produce high performance products of high quality. In the extraprise structure there are many alternative sources such as suppliers, sub system suppliers, component suppliers, "inte grators," consultants, and educational ventures as well as horizontal partners, joint ventures, and other manufacturers in the industry. A large and often major proportion of not only manufactur ing but also product and even concept develop ment may take part outside the traditional organization. The strategically most important unit of management is the extraprise network that all these organizations form, not the internal organization.

See also *industrial networks; network coordination mechanisms; outsourcing; supply chain manage ment; vertical integration*

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# F

## fail-safing

*Nigel Slack*

The concept of fail safing has emerged since the introduction of Japanese methods of operations improvement. Called *poka yoke* in Japan (from *yokeru*, to prevent, and *poka*, inadvertent errors), the idea is based on the principle that human mistakes are, to some extent, inevitable. The important issue therefore is to prevent them becoming defects. *Poka yokes* are simple and preferably inexpensive devices or systems that are incorporated into a process to prevent inad vertent operator mistakes resulting in a defect.

Typical *poka yokes* are such devices as limit switches on machines which allow the machine to operate only if the part is positioned correctly, gauges placed on machines through which a part has to pass in order to be loaded onto, or taken off, the machine, an incorrect size or orientation stopping the process, digital counters on ma chines to insure that the correct number of cuts, passes, or holes have been machined, checklists which have to be filled in, either in preparation for, or on completion of, an activity, and light beams that activate an alarm if a part is positioned incorrectly.

More recently, the principle of fail safing has been applied to SERVICE OPERATIONS. Ser vice *poka yokes* have been classified as those which "fail safe the server" (the creator of the service) and those which "fail safe the cus tomer" (the receiver of the service).

Examples of fail safing the server include color coding cash register keys to prevent incor rect entry in retail operations, the McDonald's french fry scoop which picks up the right quan tity of fries in the right orientation to be placed in the pack, trays used in hospitals with indenta tions shaped to each item needed for a surgical procedure – any item not back in place at the end of the procedure might have been left in the patient – and the paper strips placed round clean towels in hotels, the removal of which helps housekeepers to tell whether a towel has been used and therefore needs replacing.

Examples of fail safing the customer include the locks on aircraft lavatory doors, which must be turned to switch the light on, beepers on ATMs to insure that customers remove their cards, height bars on amusement rides to insure that customers do not exceed size limitations, outlines drawn on the walls of a childcare center to indicate where toys should be replaced at the end of the play period, and tray stands strategic ally placed in fast food restaurants to remind customers to clear their tables.

See also *failure analysis; failure in operations; failure measures; failure mode and effect analysis; fault tree analysis; maintenance; service recovery*

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## failure analysis

*Robert Johnston*

Failure analysis is the activity of identifying the root cause of a failure in order to understand why the failure occurred and to take steps to try to prevent it happening again. For some organiza tions this may be a large scale exercise following a major disaster such as a train crash. For many organizations it can be a daily activity to identify the causes of day to day failures and problems.

Finding the root cause of failures provides two important opportunities for organizations. First, the identification of a failure and its cause is an opportunity to improve the products or services by turning this knowledge into learning for the organization in order to help better train its employees and improve its processes and procedures. Second, an organization's response to a failure can have a significant effect on per ceived quality. In many situations, customers may well accept that things do go wrong and so the failure itself does not necessarily lead to dissatisfaction. It is usually the organization's response, or lack of it, that leads to dissatisfied customers.

Organizations sometimes may not be aware that the system has failed and thereby lose the opportunity both to put things right for the customer, internal or external, and to learn from the experience.

Many mechanisms are available to seek out failures in a proactive way. These include *in process checks* where employees check that the service is acceptable during the process itself. In some situations, however, this form of failure detection can detract from the service itself. *Machine diagnostic checks* involve testing a ma chine by putting it through a prescribed se quence of activities designed to expose any failures or potential failures. Computer servicing procedures often include this type of check. In *point of departure interviews* used at the end of a service, staff may formally or informally check that the service has been satisfactory and try to solicit problems as well as compliments. *Phone surveys* can be used to solicit opinions about products or services. *Focus groups* are groups of customers who are asked together to focus on some aspects of a product or service. These can be used to discover either specific problems or more general attitudes toward the product or service. *Complaint cards* or *feedback sheets* are used by many organizations to solicit views about the products and services. The problem here is that very few people tend to complete them. However, it may be possible to identify the respondents and so follow up on any individual problem. Finally, *questionnaires* may generate a slightly higher response than com plaint cards. However, they may generate gen eral information only within which it is difficult to identify specific individual complaints.

Several tools and techniques are available to identify and analyze failures once they have oc curred. One of the most frequently used tech niques is complaint analysis. The advantage of using complaints is that they are usually a cheap and readily available source of information about errors. On the other hand, they may not be consistent with the opinions of all customers. However, complaints are usually taken seriously as they may represent a great amount of "hidden" customer dissatisfaction since many customers do not complain. Complaint analysis involves tracking the actual number of com plaints over time, which can in itself be indica tive of developing problems. Also, by factor analyzing the content of the complaints, man agers may be better able to understand the nature of the problem as perceived by the cus tomer. PARETO ANALYSIS and cause and effect analysis, using "fishbone" (cause–effect) diagrams for example, can then be used to iden tify the most important problems and their causes (*see* QUALITY TOOLS).

Unlike complaints, which are usually unsoli cited, the CRITICAL INCIDENT TECHNIQUE actively solicits customer perceived problems. The two main advantages of this technique are, first, that it proactively seeks out problems and, second, that it may identify "problems" before they become "failures."

Other tools and techniques are usually associ ated with trying to identify and analyze failures before they occur. BLUEPRINTING is a way of systematically documenting and evaluating pro cesses that enables potential process problems to be identified and their causes investigated before the process is used. In particular it may help identify potential fail points, allow "what if" scenarios to be discussed, and may help identify where monitoring devices are best installed. Similarly, FAILURE MODE AND EFFECT ANALYSIS (FMEA) is a "checklist" procedure usu ally used in the design stage of products. This technique is used to identify the potential prob lems, assess their likelihood, and the conse quences of failure. Alternatively, system redun dancy can be used to reduce the impact of failure. Redundancy is the building in of backup systems or components in case of failure. The backup systems then take over when a failure occurs in the main system. However, this can be an expensive solution and is generally used only when the system or component breakdown will have a critical impact.

See also *fail safing; failure in operations; failure measures; fault tree analysis; maintenance; service recovery*

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**failure in operations**

*Nigel Slack*

Failure is the state that occurs when the per formance of an intended function of a process, product, or service is not met. The converse of failure is "reliability." Reliability is the probabil ity that a product, piece of equipment, or system performs its intended function for a stated period of time under specified operating conditions. Failures occur because of lack of reliability.

Not all failures are equally serious. Organiza tions therefore need to discriminate between failures and pay particular attention to those which are critical either in their own right or because they may jeopardize the rest of the op eration. A prerequisite for this is some under standing of the reasons for failures and an ability to measure the effects of the failure.

These two dimensions of failure determine the way in which operations managers treat failure. If the probability of a particular failure occurring in an operation is high and the impact of that failure is also high, it is unlikely that the operation itself will be viable. Conversely, when both the probability and impact of a failure is low, the very issue of failure will be relatively trivial. It is the spectrum between the two poles of low impact failures occurring relatively fre quently and high impact events occurring infre quently that is of most interest. The types of failure that occur relatively frequently but that individually may not have a catastrophic effect on an operation may be seen as the concern of quality management (*see* QUALITY MANAGE MENT SYSTEMS), whereas the less frequent but more significant failures are usually seen as the subject of failure management.

### Causes of Failure

Although failure in an operation can occur for many different reasons, it is convenient to clas sify failures as belonging to one of the following three classes.

- Those that are caused by faults in the mater ial or information inputs to the operation.
- Those that have their source inside the oper ation, because its overall design was faulty, or because its individual facilities (machines, equipment, and buildings) or staff fail to operate as they should.
- Those that are caused by the actions of customers.

Any failure in the input of goods and services into an operation can cause failure within the operation, either directly because of the non availability of the function they are supposed to perform through delivery or quality failures, or indirectly because of their eventual "failure in service." The more an operation relies on sup pliers of materials or services, the more it is liable to failure that is caused by missing or substan dard inputs.

The overall design of an operation can also prove to be the root cause of failure. Some design failures occur because a characteristic of demand was overlooked or miscalculated so that, al though there was no unexpected demand placed on the operation, it is unable to cope because of straightforward errors in translating the requirements of demand into an adequate design. Other design related failures occur be cause the circumstances under which the oper ation has to work are not as expected. Yet although the demands placed on the oper ation were unexpected at the point of design, they may still be regarded as design failures. Adequate design includes identifying the range of circumstances under which the operation has to work, and designing accordingly. As well as failure due to overall design, operations may become ineffective because of the failure of their technical and human resources. Failures that are directly due to staff are of two types: *errors* and *violations*. "Errors" are mistakes in judgment, in hindsight, a person should have acted in some way differently and the result is some significant deviation from normal oper ation. "Violations" are acts that are clearly con trary to defined operating procedure.

Customers can also cause failure by their misuse of the products and services that the operation has created. However, even if it is the inattention or incompetence of customers that has been the cause of failure, most organizations will accept that they have a responsibility to educate and train customers and to design their products and services so as to minimize the chances of failure.

Notwithstanding this categorization of fail ure, the origin of all failures can be viewed as some kind of internal human failure. The impli cations of this are, first, that failure can, to some extent, be controlled and, second, that organiza tions can learn from failure and modify their behaviors accordingly. The realization of this has led to what is sometimes called the "*failure as an opportunity*" concept. Rather than identi fying a "culprit" who is held to be responsible and blamed for the failure, failures are regarded as an opportunity to examine why they occurred, and to put in place procedures that eliminate or reduce the probability of their reoccurring.

In practical terms, operations managers have three sets of activities that relate to failure. The first is concerned with understanding what fail ures are occurring in the operation and why they are occurring. Once the nature of any failures is understood, operations managers' second task is to examine ways of either reducing the chances of failure or minimizing the consequences of failure. The third task is to devise plans and procedures that help the operation to recover from failures when they do occur. The first of these tasks is, in effect, a prerequisite for the other two.

See also *fail safing; failure analysis; failure meas ures; failure mode and effect analysis; fault tree analysis; maintenance; service recovery*

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## failure measures

*Nigel Slack*

There are three main ways of measuring failure: failure rates (how often a failure occurs), reliabil ity (the chances of a failure occurring), and avail ability (the amount of available useful operating time). "Failure rate" and "reliability" are differ ent ways of measuring the same thing, i.e., the propensity of an operation, or part of an oper ation, to fail. Availability, on the other hand, is one measure of the consequences of failure in the operation.

### Failure Rate

Failure rate (FR) is calculated as the number of failures over a period of time, e.g., the number of security breaches per year at an airport, or the number of failures over a defined operating time for an aircraft engine. FR is usually calculated from examining actual operating or test data. It can be measured either as a percentage of the total number of products tested or as the number of failures over time.

$$FR = \frac{\text{number of failures}}{\text{total number of products tested}} \times 100$$

or

$$FR = \frac{\text{number of failures}}{\text{operating time}}$$

Failure, for most parts of an operation, is a function of time. At different stages during the life of anything, the probability of it failing will be different. The probability of a piece of equip ment failing is relatively high when it is first used. Any small defect in the material from which the equipment was constructed or in the way it was assembled might cause it to fail. If the equipment survives this initial stage it could still fail at any point, but the longer it survives, the more likely its failure becomes. Most physical parts of an operation behave in a similar manner. The curve that describes failure prob ability of this type is called the "bath tub" curve. It comprises three distinct stages: the "infant" mortality or "early life" stage where early failures occur caused by defective parts or improper use; the "normal life" stage when the failure rate is usually low and reasonably con stant and is caused by normal random factors; and the "wear out" stage when the failure rate increases as the part approaches the end of its working life and failure is caused by the aging and deterioration of parts.

### Reliability

Reliability measures the ability of a system, product, or service to perform as expected over time. The importance of any particular failure is determined partly by the effect it has on the performance of the whole operation or system. This in turn depends on the way in which the parts of the system that are liable to failure are related. If components in a system are all inter dependent, a failure in any individual compon ent will cause the whole system to fail.

So, for example, if an interdependent system has $n$ components each with its own reliability $R_1$, $R_2 \ldots R_n$, the reliability of the whole system, $R_s$, is given by:

$$R_s = R_1 \times R_2 \times R_3 \times \ldots\ R_n$$

where $R_1$ is the reliability of component 1, $R_2$ is the reliability of component 2, and so on.

The more interdependent components a system has, the lower its reliability will be. So for a system with 400 components (not unusual in a large automated operation), even if the reli ability of each individual component is 99 per cent, the whole system will be working for less than 5 percent of its time.

An alternative (and common) measure of fail ure is the mean time between failure (MTBF) of a component or system. MTBF is the reciprocal of failure rate (in time), so,

$$MTBF = \frac{\text{operating hours}}{\text{number of failures}}$$

### Availability

Availability is the degree to which the operation is ready to work. An operation is not available if it has either failed or is being repaired following failure. There are several different ways of meas uring availability depending on how many of the reasons for not operating are included. Lack of availability because of planned maintenance or changeovers could be included, for example. However, when "availability" (A) is being used to indicate the operating time excluding the con sequence of failure, it is calculated as follows:

$$A = \frac{MTBF}{MTBF + MTTR}$$

where MTBF is the mean time between fail ure of the operation and MTTR is the mean time to repair, which is the average time taken to repair the operation from the time it fails to the time it is operational again.

See also *fail safing; failure analysis; failure in operations; failure mode and effect analysis; fault tree analysis; maintenance; performance measure ment; service recovery*

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**Table 1** Occurrence of failure

| *Description* | *Rating* | *Possible failure occurrence* |
|---|---|---|
| REMOTE probability of occurrence. It would be unreasonable to expect failure to occur. | 1 | 0 |
| LOW probability of occurrence. | 2 | 1 : 20,000 |
| Generally associated with activities similar to previous ones with a relatively low number of failures. | 3 | 1 : 10,000 |
| MODERATE probability of occurrence. | 4 | 1 : 2,000 |
| Generally associated with activities similar to previous ones | 5 | 1 : 1,000 |
| which have resulted in occasional failures. | 6 | 1 : 200 |
| HIGH probability of occurrence. | 7 | 1 : 100 |
| Generally associated with activities similar to ones which have traditionally caused problems. | 8 | 1 : 20 |
| VERY HIGH probability of occurrence. | 9 | 1 : 10 |
| Near certainty that major failures will occur. | 10 | 1 : 2 |
| **Severity of failure** | | |
| MINOR SEVERITY | | |
| A very minor failure which would have no noticeable effect on system performance. | 1 | |
| LOW SEVERITY | | |
| A minor failure causing only slight customer annoyance. | 2 | |
| | 3 | |
| MODERATE SEVERITY | | |
| A failure which would cause some customer dissatisfaction, discomfort, | 4 | |
| or annoyance, or would cause noticeable deterioration in performance. | 5 | |
| | 6 | |
| HIGH SEVERITY | | |
| A failure which would engender a high degree of customer dissatisfaction. | 7 | |
| | 8 | |
| VERY HIGH SEVERITY | | |
| A failure which would affect safety. | 9 | |
| CATASTROPHIC | | |
| A failure which may cause damage to property, serious injury, or death. | 10 | |
| **Detection of failure** | | |
| REMOTE probability that the defect will reach the customer. It would be unreasonable to expect such a defect to go undetected during inspection, test, or assembly. | 1 | 0 to 15% |
| LOW probability that the defect will reach the customer. | 2 | 6 to 15% |
| | 3 | 16 to 25% |
| MODERATE probability that the defect will reach the customer. | 4 | 26 to 35% |
| | 5 | 36 to 45% |
| | 6 | 46 to 55% |
| HIGH probability that the defect will reach the customer. | 7 | 56 to 65% |
| | 8 | 66 to 75% |
| VERY HIGH probability that the defect will reach the customer. | 9 | 76 to 85% |
| | 10 | 86 to 100% |

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## failure mode and effect analysis

*Nigel Slack*

The objective of failure mode and effect analysis (FMEA) is to identify the product or service features that are critical to various types of fail ure. It is a means of identifying failures before they happen by providing a "checklist" proced ure that is built round three key questions.

For each possible cause of failure:

- What is the likelihood that failure will occur?
- What would the consequence of the failure be?
- How likely is such a failure to be detected before it affects the customer?

Based on a quantitative evaluation of these three questions, a risk priority number (RPN) is cal culated for each potential cause of failure. Cor rective actions aimed at preventing failure are then applied to those causes whose RPN indi cates that they warrant priority.

This is essentially a seven step process:

- *Step 1*: Identify all the component parts of the products or service.
- *Step 2*: List all the possible ways in which the components could fail (the failure modes).
- *Step 3*: Identify the possible effects of the failures (downtime, safety, repair require ments, effects on customers).
- *Step 4*: Identify all the possible causes of failure for each failure mode.
- *Step 5*: Assess the probability of failure, the severity of the effects of failure, and the likelihood of detection. Rating scales that can be used to quantify these three factors are shown in table 1 (opposite).
- *Step 6*: Calculate the RPN by multiplying all three ratings together.
- *Step 7*: Instigate corrective actions that will minimize failure on failure modes that show a high RPN.

See also *fail safing; failure analysis; failure in operations; failure measures; fault tree analysis; maintenance; reliability centered maintenance; risk and operations; service recovery*

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## family bill

*Pamela Danese*

The family bill is a planning bill supporting the forecasting activity. Frequently, companies characterized by high product variety divide products into groups or families in order to simplify production planning and control activ ities. In particular, to improve the forecast ac curacy, many companies form families of products with similar demand patterns, thus shifting the forecast object from many end product configurations to few aggregate prod uct/item groups. To use aggregate forecasts they must develop a family bill, i.e., a planning bill containing a product family as a parent and more disaggregated product families as the chil dren. As an example, suppose that a manufac turer produces toys. The family bill contains the family "toys" as parent, the families "scooter," "bicycle," and truck" as first level child codes, and finally three different scooter families as second level child codes. The use of this family bill facilitates the forecasting activity. In fact, the company elaborates sales forecasts on the family "toy," and then, on the basis of the historical sales data, it evaluates a percentage coefficient (PC) for each child code within the family bill, indicating the percentage of sales volume of the child code on the total annual sales of toys. These coefficients make it possible to automatic ally disaggregate the sales forecasts of the family "toy," thus obtaining production plans related to the child codes of the family bill. Such plans are the starting points to elaborate long and medium term capacity plans.

See also *bill of materials; forecasting process; prod uct families*

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## fault tree analysis

*Nigel Slack*

This is a logical procedure that starts with a failure or a potential failure and works back wards to identify all the possible causes and therefore the origins of that failure. The fault tree is made up of branches connected by two types of nodes, AND nodes and OR nodes. The branches below an AND node all need to occur for the event above the node to occur. Only one of the branches below an OR node needs to occur for the event above the node to occur. In this manner a cause–effect "map" of the causes of failure is constructed. In oper ation, the benefits of using this type of analysis are largely in codifying a common understand ing of the intrinsic logic of failure possibility. It does not either predict failure or directly solve failure problems. Nevertheless, it does provide the basis for further action.

See also *fail safing; failure analysis; failure in operations; failure measures; failure mode and effect analysis; maintenance; service recovery*

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## Feigenbaum

*Rhian Silvestro*

A. V. Feigenbaum, who was head of quality at General Electric, originated the concept of "total quality control" (TQC). His book *Total Quality Control*, first published in 1951 under a different title, defines total quality as follows:

> The underlying principle of the total quality view . . . is that to provide genuine effectiveness, control must start with identification of customer quality requirements and end only when the product has been placed in the hands of a customer who remains satisfied. Total quality control guides the coordinated actions of people, machines, and information to achieve this goal. (Feigenbaum, 1983)

Feigenbaum introduced the concept of the "hidden plant," which he defines as the propor tion of plant capacity expended on the rework of defective parts and goods and which, he claims, typically represents between 15 and 40 percent of plant capacity. He identifies four categories of quality costs – cost of prevention, cost of ap praisal, cost of internal failure, and cost of exter nal failure – and argues that by investing in prevention, failure and eventually appraisal costs will decline, resulting in a significant re duction of total quality costs (*see* QUALITY COSTING).

Perhaps most notably Feigenbaum made a direct attack on the view that responsibility for TQC lies solely with the quality assurance or quality control function, arguing that it must be shared by all functions in the organization since they all have an impact upon the costs of quality. He describes organizational functions such as marketing, engineering, manufacturing, purchasing, installation, and service as being stages in the "industrial cycle," maintaining that improved quality in every stage of the cycle leads to cheaper quality costs in the long term.

See also *Crosby; Deming; Juran; quality; total quality management*

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## finite and infinite loading

*Nigel Slack*

There are two main approaches to the allocation of tasks to work centers (i.e., groups of people and/or machines): finite and infinite loading. Finite loading allocates work to a work center up to a set limit, normally derived from an esti mate of capacity. Work over and above this cap acity is rejected. Such an approach is particularly relevant for operations where it is possible to limit the load (e.g., an appointment system can be created) or the cost of limiting capacity is not prohibitive (e.g., a specialist sports car manufac turer can actually benefit from maintaining a finite order book). Conversely, infinite loading allocates work to a work center that may exceed its theoretical capacity constraints. Such an ap proach is particularly relevant for operations where it is simply not possible to limit the load (e.g., an accident and emergency department in a busy city hospital). In complex planning and control activities where there are multiple stages, each with different capacities and with varying mix arriving at the facilities, such as a machine shop in an engineering company, the constraints imposed by finite loading may make loading calculations complex and not worth the consid erable computational power that would be needed.

See also *capacity management; planning and con trol in operations; scheduling*


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## fit

*Michael Lewis*

Almost all of the strategic concepts discussed in the various entries of this dictionary are based upon some conceptualization of *fit* (or *align ment*): the notion that a "successful" organiza tion aligns itself with its external environment. Indeed, this idea is now so widely accepted that it has entered the realms of managerial common sense: "a simple though profound core concept . . . [s]uccessful organizations achieve a fit with their market environment and support their strategies with appropriately designed structures and management processes" (Miles and Snow, 1984). In other words, if firms generate income from customers by satisfying their requirements, operational resources therefore should be aligned with these requirements. This is essen tially the same logic that underpins the dominant structure–conduct–performance (SCP) para digm in competitive strategy (made famous by Porter's "5 forces" model). This generalized framework argues that any firms' performance will be defined by its conduct (strategy and op erations) in the context of particular market structures.

Two basic modes of fit can be identified.

1 *Outside/In*. An operation can identify existing market requirements and then align its resources to match them. This dom inant approach has a number of intrinsic advantages, not least of which is the sheer availability of practical tools and techniques for classifying and identifying market re quirements. This model also falls neatly into the traditional hierarchy of strategies whereby operations' role is to support pre determined market decisions.

2 *Inside/Out*. Alternatively, an operation can begin by analyzing the relative strengths and weaknesses of its underlying resources and only then seek market requirements that match them.

Figure 1 illustrates these twin concepts of fit. The vertical dimension represents the nature and level of market requirements either because

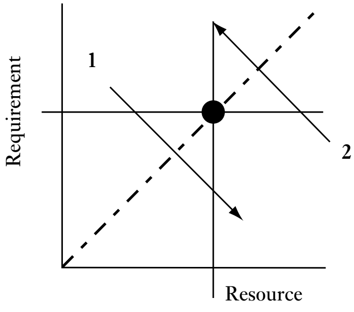


**Figure 1** Fit between operational resources and market requirements

they reflect the intrinsic needs of customers or because customers' expectations have been shaped by the firm's marketing activity. This includes such factors as strength of brand/repu tation, degree of differentiation, extent of plaus ible market promises, and so on. Movement along the dimension indicates a broadly en hanced level of market performance or market capabilities. The horizontal scale represents the level and nature of the firm's operations resource and processes capabilities. This includes such things as the performance of the operation in terms of its ability to achieve competitive object ives, the efficiency with which it uses its re sources, the ability of the firm's resources to underpin its business processes, and so on. Again, movement along the dimension indicates a broadly enhanced level of "operations per formance" and operations capabilities. The pur pose of "fit" is to achieve an approximate balance between "market performance" and "operations performance." So when fit is achieved, firms' customers do not need, or expect, levels of operations performance which it is unable to supply. Nor does the firm have operations strengths that are either inappropri ate for market needs or remain unexploited in the market. The diagonal line in figure 1 there fore represents a "line of fit" with market and operations in balance. It is important to stress that this is a conceptual model, intended merely to illustrate the concept of fit.

### Achieving Fit in Practice

Beyond recognizing the need for market/re source alignment, there are many practical for mulation questions. In generic terms, this means understanding what it means for strategy to be comprehensive, insuring there is internal coher ence between different decision areas, insuring that resource decisions correlate with the prior ity given to performance objectives, and recog nizing the impact of broader financial and competitive priorities.

### Comprehensiveness

In seeking to achieve operations fit, the notion of "comprehensiveness" is a critical first step. Business history is littered with world class companies that simply failed to notice the po tential impact of, for instance, new PROCESS TECHNOLOGY, or emerging changes in their supply network. Also, many attempts to achieve fit have failed because operations have paid undue attention to only one of the key decision areas. This process should also address the need to balance structural (those that define its over all tangible shape and architecture) and infra structural decisions (those that affect the people, systems, and culture which lubricate the decision making and control activities of the operation). Although there is some ambigu ity as to which decisions are structural and which are infrastructural, structural decisions are normally taken to include those concerned with capacity, facilities and plant, technology, and VERTICAL INTEGRATION, whereas infrastructural decisions include those con cerned with planning and control, quality man agement, new product or service development (*see* NEW PRODUCT DEVELOPMENT PRO CESS), and PERFORMANCE MEASUREMENT (*see* STRUCTURAL AND INFRASTRUCTURAL DECISIONS).

### Coherence

In making a strategy comprehensive it is also important to consider the dynamic process of implementation over time. As a comprehensive strategy evolves over time, different tensions will emerge that threaten to pull the overall strategy in different directions. This can result in a loss of coherence. Coherence is when the choices made in each decision area do *not* pull the operation in different directions. For example, if new flexible technology is introduced which allows products or services to be customized to individual clients' needs, it would be "incoherent" to devise an organization structure that did not enable the relevant staff to exploit the technology because it would limit the effective flexibility of the operation. Moreover, for the investment to be effective, it must be accompanied by an organizational structure that deploys the organization's skills appropriately, a performance measurement system that acknowledges that flexibility must be promoted, a new product/service development policy that stresses appropriate types of customization, a supply network strategy that develops suppliers and customers to understand the needs of high variety customization, a capacity strategy that deploys capacity where the customization is needed, and so on. In other words, all the decision areas complement and reinforce one another in the promotion of that particular performance objective. The main problem with achieving coherence is that so many decisions are made which have a strategic impact that it is relatively easy to make decisions that inadvertently cause a loss of coherence.

### Correlation

Strategy in different decision areas (i.e., technology, supply chain, performance measurement, etc.) should correlate with the priority of each performance objective. So, for example, if cost reduction is the main organizational objective for an operation, then its process technology investment decisions might err toward the purchase of "off the shelf" equipment from a third party supplier. This would reduce the capital cost of the technology and may also imply lower maintenance and running costs. Of course, making such a decision will also have an impact on other performance objectives. An off the shelf piece of equipment may not, for example, have the flexibility that more "made to order" equipment has. Also, the other decision areas must correspond with the same prioritization of objectives. If low cost is really important, then one would expect to see capacity strategies that exploit natural economies of scale, supply network strategies that reduce purchasing costs, performance measurement systems that stress efficiency and productivity, CONTINUOUS IMPROVEMENT strategies that emphasize continual cost reduction, and so on.

### Criticality

In addition to the difficulties of insuring coherence between decision areas, there is also a need to include financial and competitive priorities. Although all decisions are important, in practical terms some resource/requirement intersections are more critical than others. The judgment over exactly which "intersections" are particularly critical is a pragmatic one that must be based on the particular circumstances of an individual firm's operations strategy. However, in practice, one can ask questions such as: If flexibility is important, of all the decisions we make in terms of our capacity, supply networks, process technology, or development and organization, which will have the most impact on flexibility?

See also *dynamic capabilities; manufacturing strategy process; operations strategy; planning and control in operations; risk and operations*

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## fixed position layout

*David Bennett*

A fixed position layout is one of the three basic options for laying out facilities to produce goods or deliver services, the other options being a PROCESS LAYOUT or PRODUCT LAYOUT. A fourth option, the CELL LAYOUT, is actually a hybrid facility arrangement that combines some of the principles of fixed position and product layouts.

The term "fixed position" implies that the product remains (more or less) stationary and all materials, equipment, labor, instructions, etc. are brought to the place of work. The service equivalent might be where the "customer" remains stationary and the various elements of the service are delivered to the point where the customer is located. The labor resource can comprise an individual worker or might involve GROUP WORKING. Fixed position layouts are usually a feature of batch production, or jobbing operations. They offer a number of advantages, the most important of which is product FLEXI BILITY. This is achieved because the machines and equipment used in fixed position layouts are mostly of a general purpose nature, the workers are usually multiskilled, and several different products (or services) can be produced simultan eously and in parallel.

In some cases, use of a fixed position layout is unavoidable as a result of the sheer size and nature of the product being made (e.g., con struction of an oil rig) or because the product will remain stationary in the position it was made (e.g., a bridge). In other cases, however, there is a genuine choice of layout and a fixed position approach is taken because of the advantages it offers. For example, motor vehicle assembly sometimes uses a fixed position layout, coupled with group working, because it enables a large variety of finished products to be produced more easily. Also the multiskilling and greater auton omy of the workforce, together with a focus on the entire product rather than a small part of it, can provide the motivation to improve quality and labor efficiency. In service provision a fixed position layout (where the customer remains stationary) has the advantage of offering greater convenience to customers. For example, office workers may use a sandwich delivery service to save the time of going out to lunch, while telephone home banking avoids the need for customers to visit their local branch.

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## flexibility

*David Upton*

Flexibility has become an increasingly important aspect of operations for a number of reasons. First among these is the increasing demand from customers for rapid response, broad prod uct ranges, and the ability to customize products for particular solutions. Second is the increasing capability of manufacturing technology to de liver greater product variety or small batch sizes without punitive expense. Finally, as busi nesses are required to change more frequently and radically, *strategic* flexibility (i.e., the ability to make longer term changes) has become increasingly important. It has long been recog nized that there are many different mani festations of operational flexibility and that a clear definition of the flexibility of concern was an important factor in managing and improving it.

### Types of Flexibility

Much of the early interest in flexibility con cerned how the different types of flexibility should be characterized and resulted in several typologies of flexibility. These typologies usu ally classify flexibility at one of four levels of analysis:

- the firm, where flexibility issues concern the ability of the whole organization;
- the operations function or total system, where flexibility issues concern the ability of the operations function to change the nature, volume, and timing of its outputs;
- the cell or small system, where flexibility issues concern, e.g., the variety of products able to be made, or the time taken to change from the manufacture of one product to an other; and
- the resources of operations, where flexibility issues again concern the variety of tasks that

individual machines or people perform and the nature of changing tasks.

Most typologies explore the two intermediate levels of analysis. For example, Browne et al.'s (1984) typology is the most comprehensive of the typologies at the cell level. It defines flexibil ity as a set of eight capabilities.

1 *Machine flexibility*: the ability to replace or change tools in a tool magazine, and mount the required fixtures, without interference or long setup times. It is the ease of the system in making changes required to produce a given set of part types.
2 *Process flexibility*: the ability to vary the stages or activities necessary to complete a task. This allows several different tasks to be completed in the system, using a variety of machines.
3 *Product flexibility*: the ability to change over to produce a new product, within the defined parts range, economically and quickly (*see* SETUP REDUCTION).
4 *Routing flexibility*: the ability to vary machine activity sequences, e.g., to cope with break downs, and to continue producing the given set of part types. This ability exists when there are several viable processing routes or when each operation can be performed on more than one machine.
5 *Volume flexibility*: the ability to operate a cell or system cost effectively at different pro duction volumes (*see* AGGREGATE CAP ACITY MANAGEMENT).
6 *Expansion flexibility*: the capability of build ing a system and expanding it as needed, easily and modularly.
7 *Process sequence flexibility*: the ability to inter change the ordering of several operations for each part type.
8 *Production flexibility*: the ability to vary the part variety quickly and economically for any product that a cell can produce. A cell does not attain production flexibility until all the other flexibilities have been achieved.

At the operations function or total system level different typologies become more appropriate. One such distinguishes between four types of flexibility.

1 *Product flexibility*: the ability to introduce and produce novel products or services or to modify existing ones.
2 *Mix flexibility*: the ability to change the range of products or services being made by the operation within a given time period.
3 *Volume flexibility*: the ability to change the level of aggregated output.
4 *Delivery flexibility*: the ability to change planned or assumed delivery dates.

At a more fundamental level, some have argued that ex ante typologies of flexibility may by useful in a general sense, but that some forms of flexibility are idiosyncratic to the particular situation at hand. Upton (1994), drawing on Slack's earlier work, suggests a process for iden tifying the most salient forms of flexibility for particular situations. Three questions, according to this work, must be addressed to identify which particular manifestation of flexibility is being managed.

- *What changes?* Flexibility is about the ability to change. The first step, therefore, is to identify what, precisely, is changing. This could be a dimension as generic as "produc tion volume." It could also be a dimension more parochial to the situation at hand (e.g., bottle size in a contract filling operation).
- *Over what time horizon does the change occur?* Is this an *operational* flexibility, in which changes happen day to day, as a matter of course? Is it a *tactical* flexibility, in which changes happen in the course of normal business, but only every few months or so (as might be the case in a seasonal business)? Is it a *strategic* flexibility, in which case the change happens very infrequently, either proactively or in response to long term changes?
- *What is the form of the flexibility?* Is it "range" or the ability to accommodate large changes on the dimension of interest? Is it "mobility" or the ability to switch from one place on that dimension to another without significant penalty? Is it "uniformity" or the ability to

operate with indifference at any point in a given range?

Flexibility, as described immediately above, rep resents internal operational capabilities. How ever, a firm that chooses to compete externally through its flexibility may not require internal flexibility to achieve its goal. Conversely, firms that apparently compete on an "inflexible" di mension – such as low cost – may make great use of internal flexibility to achieve their objectives. For example, a "flexible" company aiming to offer a wide range of products can achieve its objective through a collection of very focused plants, none of which has much internal flexibil ity in terms of its ability to produce different products on a day to day basis. At the same time, a company choosing to compete through low cost might achieve such an objective by insuring that all its operations have the ability to produce at low cost no matter what economic conditions (and hence production volumes) prevail.

Measuring Flexibility

In spite of its importance, the ability to meas ure flexibility in a generic way is still poorly developed. However, since measurement is at the heart of the ability to improve, some at tempt must be made, though it is likely that appropriate measures will be developed locally and will be fashioned to the particular kinds of flexibility of interest. It may be useful, there fore, to point out some of the issues that make flexibility such an elusive capability to measure.

First, flexibility is often about the *potential* to do something, rather than a demonstrated abil ity. As such, it is often difficult to measure flexibility objectively – one may have to resort to subjective assessments of what one *believes* to be possible.

Second, the multifarious nature of flexibility and the difficulty of definition described earlier often confuse measurements: for example, should the firm measure the external (cus tomer facing) effects of its flexibility (such as response times)? Or should it instead measure internal capabilities that might support those external qualities, such as quick changeover times?

Some attempts have been made to identify the drivers of manufacturing flexibility, and in doing so have attempted to identify and quantify cer tain types of internal capability and relate them to various plant characteristics, such as work force experience and degree of computer inte gration (Upton, 1997). However, the extent to which such results can be generalized may be limited, and such empirical work merely pro vides an example of how one might pinpoint the underlying drivers of internal flexibility in one particular situation. Flexibility, then, remains an elusive but important concept in operations, and one that will continue to be the focus of researchers and practitioners for many years to come.

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## flexible manufacturing system

*John Bessant*

A flexible manufacturing system (FMS) is a configuration of semi independent workstations connected by automated materials handling and machine loading technologies. When the first emerged, such systems were positioned as offering greater FLEXIBILITY because of the connectivity afforded by IT control and the use of multifunction robots in manipulating of parts and tools within a manufacturing cell. Although much early interest was focused on engineering industries as prime users of FMS, the technol ogy also found applications in many other sectors including clothing and footwear, ceram ics and furniture manufacturing. Adoption was driven by an emphasis on increased throughput and reduced work in progress inventory via faster changeovers, on capital saving (integrated systems replace many discrete machines), and space saving. Interestingly, labor saving was rarely seen as significant, especially given the associated infrastructure costs of FMS (i.e., pro gramming, maintenance, engineering, training, etc.). The parallel emergence of FMS and cellu lar manufacturing principles provided both (1) the most appropriate context for successful ex ploitation of FMS and (2) evidence that many of the benefits ascribed to the technology could be realized by simple process redesign.

See also *advanced manufacturing technology; cell layout; computer integrated manufacturing; pro cess technology; robotics*

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## focus

*Stuart Chambers*

Focused (manufacturing) operations, as a con cept, was first described by the American aca demic Wickham Skinner (1974). Based on his empirical research, Skinner claimed that a fac tory that focuses on a narrow product mix for a particular market niche will outperform the conventional plant which attempts a broader mission. Because its equipment, supporting systems, and procedures can concentrate on a limited task for one set of customers, its costs, and especially its overheads, are likely to be lower than those of a conventional plant.

Skinner added that while such operations are relatively rare in practice, they do offer the op portunity to gain competitive advantage because the entire operation is focused on accomplishing the objectives required by the company's overall business and marketing strategies. Skinner's work on focus has been a major influence on manufacturing strategy methodology develop ments in which different market requirements are recognized and reflected in the design of the operations system.

There are a number of ways that focus can be designed into operations. One approach is to restrict the range (variety) of products or ser vices offered, so that only higher volume re quirements have to be produced. Although this can restore some economies of scale and reduce overhead costs, it is based on the view that the retained markets will be sufficiently large and provide adequate return on investment. Most organizations decide to retain all or most of the existing product and market coverage, and so can only advance focus within the operations function. This is achieved either by reallocation of the products within the existing operation facilities, or by redesign of the facilities, usually by division, to allow the development of smaller, more focused operations.

Several approaches to focus have been identified.

- *Focus by volume*: This approach involves the allocation of products or services to separate facilities on the basis of their volumes. The high volume operations can then concen trate on exploiting the economies of scale, while one or more lower volume facilities develop other competencies such as flexibil ity or speed. Many operations have always used this approach, for example, to separate prototype production from mainstream production. Focus by volume implies that products should move between facilities at different stages of their life cycles, which some writers believe to be disadvantageous as it involves potential duplication of pro cesses and tooling, and the need to transfer product knowledge between facilities.

- *Focus by process*: Where the production of specific products or services involves the use of specialized skills, or capital intensive technologies, it may be preferable to form process based focused facilities, thereby avoiding unnecessary duplication of re sources and maintaining high utilization levels. One form of this type of focus uses PRODUCT FAMILIES within a CELL LAYOUT, where the transformation re sources are brought together for products with similar processing requirements.
- *Focus by market*: Separation of facilities by market (or customer) creates the op portunity to provide specialized resources and infrastructure for the exact require ments of that market. This dedication of resources should provide enhanced respon siveness to customers' needs and priorities, opening up the opportunity for them to communicate directly with the operations function. However, this approach requires an agreed and sustained level of demand so that capacity can continue to be used effectively. Market focused operations may lose flexibility in terms of volume and mix, and may require considerable dupl ication of resources and dilution of technical skills.
- *Focus by product*: An extreme case of focus is where a single product or a group of similar products or services is produced in a dedi cated facility. In effect, this combines the advantages of focus by market *and* process; conflicts of objectives are eliminated and resources can be used to enhance quality conformance and reduce costs. Where volumes are sufficiently high, dedicated high volume processes can be employed, ex ploiting the economies of scale. Focusing by product, however, can create inflexibility; new product introductions may be more dif ficult, and such systems are vulnerable to volume and mix variations. This approach to focus seems to be most appropriate in stable, high volume environments.
- *Focus by market requirements*: Skinner (1974) contended that a focused factory should en compass a consistent and limited set of market demands, and one set of internally consistent, non compromised criteria for success. Other types of focus may only par tially satisfy this requirement. For example, even within one market, the exact customer requirements or ORDER WINNERS AND QUALIFIERS criteria may vary widely. Where possible, focus should be planned around grouping together sets of products that have similar order winning criteria, such as the speed, quality, or cost require ments of the market. This also creates the greatest potential for creating appropriately designed (effective) and efficient infrastruc tures to support each focused unit, thereby minimizing overheads. A significant prob lem with focus by order winning criteria is that these usually change as a product pro gresses through its life cycle, and so products and tooling must be moved from plant to plant. Where volumes are expected to remain high for a period, product focus may be preferred as this can give the lowest costs for low variety products.
- *Focus by geography*: For many organizations it is necessary to conduct operations in close proximity to the geographic location of the customer. This is particularly the case where value is added through direct interaction with the customers, as with many services. Equally, for products where the logistic costs are greater than the economies of scale bene fits, there can be advantages of focusing manufacturing on the requirements of the location within economic transport distance of the site (*see* LOGISTICS).

In practice, organizations may decide to use a combination of focused operations; e.g., product focus for high volume, repetitive products or services; a market focus for specific customers or groups of customers with similar operational requirements; focus by volume for other prod ucts; and focus by order winners where there are some specific requirements for fast delivery or special quality specifications.

Although most literature is based on manu facturing operations, the concepts and principles of focus apply equally to SERVICE OPER ATIONS. For example, some very successful services in diverse sectors are based on product focus: a narrow range of services provided by simple, low overhead facilities and infrastruc tures, designed to exactly meet the needs and expectations of the customers.

It is generally accepted that the main sources of the benefits of focus derive from clarity of mission, repetitive operations tasks, and the re duction in conflict between objectives which results in complexity and ineffectiveness. Some writers also claim that significant benefits come from better matching of product and process technologies to each other and to market re quirements, enhanced asset management (particularly of inventory), and improved inter functional communication and performance. Other claimed benefits of focus include greater efficiency, increased effectiveness, and enhanced market orientation; therefore cost comparisons alone could be misleading. More significant are the benefits that should manifest them selves in long term profitability, but this is difficult to assess conclusively in fluctuating business cycles. Alternatively, inter company or inter plant comparisons could be useful but depend heavily on exact comparability of their measurement systems.

However, there is relatively little conclusive evidence to support the claims for benefits of focus. Nevertheless, the concept has widespread intuitive support among both academics and practitioners. The lack of factual evidence for the benefits of focus can be attributed to the difficulties of collecting such evidence. Some re search evidence does exist. One study, provided by the Boston Consulting Group, is reported by Hayes and Wheelwright (1984). In one industry, researchers found a significant inverse relation ship between the number of product lines pro duced and the operating margin achieved. Within a seven site process intensive business, the highest margin achieved was at the sites where there was the narrowest product range, and the fewest customers served. Within one plant, as product range was progressively reduced, and average product volume was increased over time, the standard cost reduced significantly.

The concept of focus can be applied at various levels within organizations, and has its parallels in other subjects. Much of the strategic manage ment literature supports moves toward better corporate focus, claiming that businesses that try to cover too wide a field are likely to be disadvantaged compared to those that have focused on the needs of niche segment(s). Most literature on focus is appropriate at plant level. However, focus can also be achieved by the physical division of plants into smaller, relatively self contained smaller units, often known as "plants within plants" (PWP). Ideally, these PWPs should include most of the processes and supporting functions to enable them to work independently and to interface directly with suppliers and customers. Similarly, the concept of cellular manufacture could be regarded as an extension of focus at the micro level of operations.

See also *flexibility; inventory management; oper ations strategy; process technology; service strategy; trade offs; volume*

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### forecasting process

*Pamela Danese*

The forecasting process encompasses all the ac tivities put into place to provide, disseminate, control, and monitor the forecasts within the firm (Mentzer and Bienstock, 1998; Moon and Mentzer, 1998). The main phases/activities of the forecasting process are:

1 the definition of forecasting objectives, im plying the definition of the forecast objects, horizon, and the company targets;
2 the collection of the data necessary to elabor ate the forecasts;
3 the forecasts elaboration;
4 the review of the elaborated forecasts on the basis of qualitative information;
5 the dissemination of the forecasting results to all the users; and, finally,
6 the monitoring of the forecasting process, i.e., an important starting point to organize improvement interventions.

See also *capacity management; collaborative plan ning, forecasting, and replenishment; newsvendor problem; planning and control in operations; sched uling*

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# G

## Gantt chart

*Nigel Slack*

A Gantt chart is a simple device, first devised by H. L. Gantt in 1917, which represents time as a bar, or channel, on a chart. Often the charts themselves are made up of long channels into which colored pieces of paper can be slotted to indicate what is happening with a job or a work center; these may be called schedule boards. The start and finish times for activities can be indi cated on the chart and sometimes the actual pro gress of the job is also indicated on the same chart.

Gantt charts provide a simple visual represen tation of what should be happening and what actually is happening in an operation, and can be used to "test out" alternative schedules, es pecially when using moveable pieces of paper. However, the Gantt chart is in no way an optimizing tool. It merely facilitates the devel opment of alternative schedules by communi cating them effectively.

See also *last planner; project control; project man agement*

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## generic manufacturing strategies

*Mike Sweeney*

To describe a manufacturing strategy as "gen eric" implies that a single and unique type of manufacturing strategy has generally been adopted by a substantial number of manufactur ing businesses. This may, at first, seem improb able given the considerable diversity of manufacturing companies and the variety of products that they produce.

To assess the probability of the existence of a small number of generic manufacturing strat egies, consideration must be given to how a manufacturing strategy is designed. Skinner (1969), in his pioneering research of the manu facturing strategy management process, recom mends that the manufacturing capabilities of an organization should be congruent with the com petitive strategy of a firm. Porter (1980) claims that organizations of all types implement generic competitive strategies; it therefore seems logical that their implementation would induce the establishment of a common set of generic manu facturing strategies.

The concept of generic manufacturing strat egies fulfilling an ideological fit with generic competitive strategies is helpful to the creation of a vision of how the manufacturing capabilities of a firm should be developed. A framework that links generic competitive strategies with generic manufacturing strategies would therefore pro vide an aid to the manufacturing manager when planning the long term development of the manufacturing capabilities of a company.

For these reasons, a considerable amount of research has been carried out to investigate whether generic manufacturing strategies can be identified and what competitive advantages are enabled by their implementation.

Stobaugh and Telesio (1983) carried out a study and review of a hundred case studies. They found three groups of international manu facturers – cost driven, technology driven, and market driven. Miller and Roth (1994) used American Manufacturing Futures data to deter mine empirically a taxonomy of manufacturing strategies. From their statistical analysis they distinguished three groups of manufacturing strategies, which they named caretakers, mar keteers, and innovators. Their definitions of these manufacturing strategy groupings were as follows:

1 *Caretakers* tend to compete on price but they were notable for the low levels of importance that they ascribe to manufacturing capabil ities and improvement programs.
2 *Marketeers* seek to obtain broader distribu tion, to offer broader product lines, and to be responsive to changing volume require ments. Marketeers plan on strengthening their manufacturing operations through infrastructural change.
3 *Innovators* place emphasis on their ability to make quick changes to product design and focus on providing high performance products.

Miller and Roth found that although the tax onomy they propose is influenced by industry type, it is not dominated by it, and it applies to a broad number of competitive circumstances. De Meyer (1992) carried out a similar empirical study. The data source for this research was the 1987 and 1988 European Manufacturing Futures Survey. De Meyer also identified three clusters of organizations with similar emphasis given to their competitive priorities and manu facturing action plan. His general conclusion was that the European manufacturing innovators coincide to a certain extent with the North American innovators. The second group, which he defined as the marketing oriented group, was described as "having quite a number of analogies with the North American caretakers, but has in its priorities something of the market eers." The third group De Meyer labeled as the high performance products group. This group was defined in the following way:

> The third group of focused manufacturers emphasizes the performance of their products. They seem to be a bit more oriented toward the deployment of technology in their emphasis on computer-aided design and flexible manufacturing systems [*see* COMPUTER-AIDED DESIGN; FLEXIBLE MANUFACTURING SYSTEM], and strive for a good production process characterized by worker safety.

Concurrent with these empirical research stud ies, Sweeney (1993) was developing a conceptual framework linking generic competitive strategies with their equivalent manufacturing strategies which derived from case studies. This concep tual framework is shown in figure 1. The figure shows four generic manufacturing strategies,

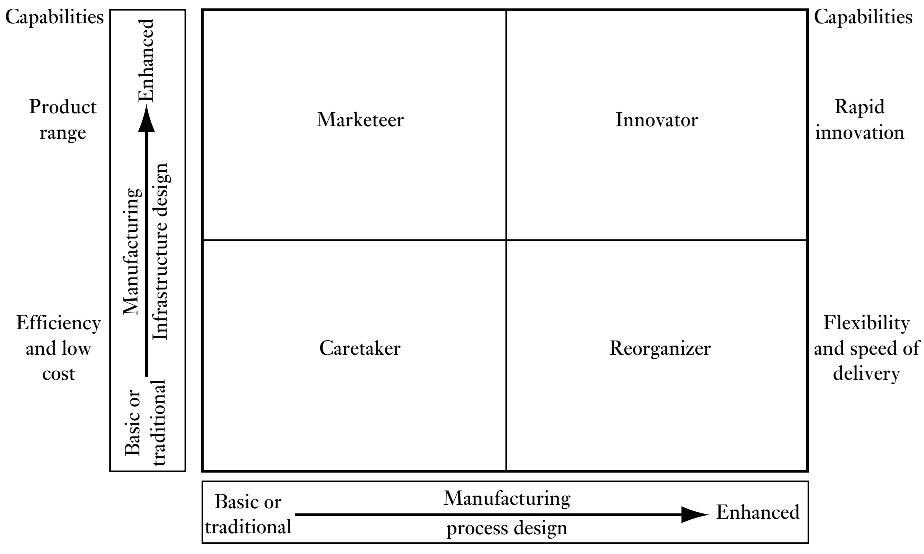


**Figure 1** Generic manufacturing strategies

**Table 1** Comparison of the construction of two types of manufacturing system

| | *Difference between manufacturing systems* | |
|---|---|---|
| *Characteristics of the system construction* | *Classical manufacturing system (Hayes and Wheelwright, 1984)* | *Global manufacturing network system (adapted from Shi and Gregory, 1998)* |
| **Structural elements** (static levers controlling the architectural configurations of corporate international manufacturing system) | 1 *Capacity*: amount, timing, type<br>2 *Facilities*: size, location, specialization<br>3 *Technology*: equipment, automation, linkage<br>4 *Vertical integration*: direction, extent, balance | 1 *Factory's characteristics*: (as whole of left column)<br>2 *Geographic dispersion*: factory location and dispersion features<br>3 *Vertical integration*: mechanisms to integrate the internationally dispersed factories along the product family's value added chains<br>4 *Horizontal coordination*: mechanisms to coordinate the dispersed factories which are at the same position on the product family's value added chain |
| **Infrastructure elements** (dynamic levers controlling the operational mechanism of corporate international manufacturing system) | 5 *Workforce*: skill level, wage policies, employment security<br>6 *Quality*: defect prevention, monitoring, intervention<br>7 *Production planning/material control*: sourcing policies, centralization, decision rules<br>8 *Organization structure*: structure, control/reward system, role of staff groups | 5 *Dynamic response mechanism*: global opportunity exploration, identification, and quick responsiveness to customers' new requirements<br>6 *Manufacturing resources mobilization*: product life cycle (PLC) dynamics, knowledge transfer in international manufacturing networks, and manufacturing resource mobilization<br>7 *Operations and control mechanisms*: network order loading, optimization, daily coordination and control, and management information and communication infrastructures<br>8 *Capability development and evolution*: global network learning capability from different nations and evolutionary adaptation |

three of which are those created by Miller and Roth. The fourth, the reorganizer strategy, is intended to convey that a change to the produc tion process to increase flexibility and delivery speed is a key priority for those implementing this strategy.

See also *flexibility; operations strategy; manufac turing strategy; manufacturing strategy process*

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## global manufacturing network

*Yongjiang Shi*

The global manufacturing network is a geo graphically dispersed production or an oper ations subsidiary, similar to a factory, network for a product family (*see* PRODUCT FAMILIES), and owned or partly owned by a multinational corporation.

Such networks have three basic characteris tics:

1 *Ownership boundary*. The global manufactur ing network is usually referred to as an intra firm network, or more strictly restrained within a strategic business unit (SBU) or product family. From this perspective, the global manufacturing network is not a global supply chain or network, which usually belongs to different companies and is called an inter firm network.

2 *Geographic dispersion*. Although terms such as international, multinational, trans national, and global are exchangeable, "global" is usually defined as being more dispersed worldwide and more interactively coordinated between factories (Fleenor, 1993).

3 *Networking relationship*. Because of its geo graphic dispersion, relationships, such as VERTICAL INTEGRATION and horizontal coordination along the internal value added chain, as well as headquarters and overseas subsidiaries, become very critical and com plex. For a long time, centralization or de centralization have been addressed between headquarters and subsidiaries (Stopford and Wells, 1972). But in the 1980s, Bartlett and Ghoshal (1989) suggested that, from know ledge and capability perspectives, overseas subsidiaries should be recognized as differ ent types of centers of excellence. These centers of excellence could be integrated and coordinated through the business value chain and managerial mechanisms in order to achieve network potentials without TRADE OFFS between centralization or decentraliza tion. Ferdows (1997) explored the strategic roles of different factories in the network and linked the roles to capabilities, which dem onstrates the subsidiary's role or function in the global manufacturing network. Shi and Gregory (1998) developed a more holistic way to classify and map global manufactur ing networks in terms of geographic disper sion and coordination. There are eight different types of configurations identified to represent their structural and capability characteristics.

In contrast to the classical operations manage ment focus, the global manufacturing network can be recognized as a new type of manufactur ing system with an international extension of system boundaries and new constructions, as shown in table 1 (Shi and Gregory, 1998). Be cause of the new structures and mechanisms, the strategic functions or capabilities of global manufacturing networks are also fundamentally different from the capabilities of the classical factory based manufacturing system. The new capabilities of the network are identified as strategic resource accessibility, thriftiness ability, manufacturing mobility, learning ability, and network supportiveness.

See also *international location; location; outsourcing; supply chain management*

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## group working

*David Bennett*

Group working is a type of work organization that emerged as an alternative to forms that were based on individual working, which are, in turn, often based on DIVISION OF LABOR and specialization. Organizing work on a group or team basis was not an entirely new idea when it became popular. Many traditional craft based industries have always used group working because of the benefits it brings in terms of better communications and control of the process. This in turn has been found to influence product quality, one of the most important factors in such industries.

With the advent of SCIENTIFIC MANAGEMENT, work organization became less craft based and increasingly fragmented and controlled. Industries using the traditional forms of organization became the rarity and differentiation and predetermination emerged as the principal characteristics of industrial work.

More recently, however, there has been a significant reversal in thinking. Problems have been encountered with types of work organization based on differentiation, such as task oriented work on lines and process oriented work in functional workshops. These problems result from the alienation of people who work in these types of system. As a result there is often high labor turnover, recruitment problems, and high absenteeism rates, and quality can suffer. Sometimes workers have even been known to sabotage equipment or products as a way of demonstrating their frustration and boredom brought on by the monotony associated with repetitive, differentiated work.

Using group working as an alternative was first put forward in countries where industrial workers had a high standard of education, principally in Scandinavia. The effect of these higher education standards was a demand for more fulfilling work. Norway, for example, experimented with group working in the steel and papermaking industries during the 1960s and Sweden's experiments in the automotive industry during the 1970s are well known. Today, group working is well established and complete production plants have been designed and built using the concept, whereas earlier examples were based on reorganizing the work within existing facilities.

To be effective, group work should be supported by a technical system that will allow a high degree of task FLEXIBILITY and autonomy. Where this has been achieved, the term "autonomous work group" is sometimes used. Such technical systems will be based on the principle of parallel rather than sequential work stations. Sometimes the work can be carried out while the product is stationary in what is known as a "dock" system. The material handling equipment will also allow workers to control the pace, and even the routing, of products.

AUTOMATED GUIDED VEHICLES (or AGVs) are often used rather than fixed speed conveyors.

A particular consideration with group working is the need for an appropriate system of payment for this type of work organization. Conventional payment systems, particularly those based on an individual financial incentive, are usually inappropriate since they do not take account of the interdependence of group members. A better payment system would probably comprise several components depending on the nature of work organization and the motivational and reward factors being emphasized.

Some of the more relevant features might be an individual element based on job evaluation (taking into account factors such as education, training, range of acquired skills, extra responsibilities, timekeeping record, etc.), a group element based on delegated responsibilities (these might include production planning, quality responsibility, cost accounting, administration, and social responsibilities such as not rejecting other group members), and a results related element which is possibly paid on a plant wide basis (this might take into account the total cost of production workers, cost of staff, number of rejects, amount of rework, use of operational supplies and tools, added material, store value, and a quality index).

A more recent development in group working is that of team based work organization (sometimes called self managed work teams). This is where staff, often with overlapping skills, collectively perform a defined task, but also have a high degree of discretion over how the task is performed. The team would typically control such things as task allocation between members, SCHEDULING work, quality measurement and improvement, and sometimes the hiring of staff. To some extent most work has always been a group based activity. The concept of teamwork, however, is more prescriptive and assumes a shared set of objectives and responsibilities. Groups are sometimes described as teams when the virtues of working together are being emphasized, such as the ability to make use of the various skills within the team.

Teams may also be used to compensate for other organizational changes such as the move toward flatter organizational structures. When organizations have fewer managerial levels, each manager will have a wider span of activities to control. Teams that are capable of autonomous decision making may have an advantage in these circumstances. Effective decision making, however, may require a very broad mix of skills within the team.

The benefits of teamwork can be summarized as:

- improving productivity through enhanced motivation and flexibility;
- improving quality and encouraging innovation;
- increasing satisfaction by allowing individuals to contribute more effectively;
- making it easier to implement technological changes in the workplace because teams are willing to share the challenges this brings.

However, teamwork is held by some authorities to be not only difficult to implement successfully, but also liable to place undue stress on the individuals who form the teams. Some teams are formed because more radical solutions, such as total reorganization, are being avoided. Teams cannot compensate for badly designed organizational processes, nor can they substitute for management's responsibility to define how decisions should be made. Often teams are asked to make decisions but are given insufficient responsibility to carry them out. In other cases teams may provide results, but at a price. Perhaps most seriously, teamwork is criticized for substituting one sort of pressure for another. Although teams may be autonomous, this does not mean they are stress free. Top down managerial control is often replaced by excessive peer pressure, which is in some ways more insidious.

See also *empowerment; job design; job enlargement; job enrichment; job rotation; method study; teleworking; work organization*

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## guest engineering

*Michael Lewis*

The last decade has seen the emergence of a range of more cooperative strategies as firms acknowledge a much higher level of interdependence with their suppliers. Although most research focuses on the flow of physical products through the "supply network," researchers and practitioners increasingly argue that knowledge is the critical resource for competitive performance. As a result there is a growing body of work exploring supplier involvement in product design and innovation more generally (Hartley, Zirger, and Kamath, 1997; Ragatz, Handfield, and Scannel, 1997). Although "developing, improving, adopting, protecting and renewing knowledge" (Badaracco, 1991: 1) has always required inputs from the supply market beyond the boundaries of the firm, today's more cooperative strategies are a function of changing competitive circumstances. It is increasingly common to second employees of a supplier (or customer) company, familiar with that firm's product and/or PROCESS TECHNOLOGY, to the customer (or supplier) for a period of time. The objectives might include DESIGN FOR MANUFACTURE, enhancing QUALITY, and improving technical performance. Similarly, customers may send their own engineers to supplier firms in order to facilitate improvements or learn of supplier developments that could be incorporated into their own new products. This exchange of technical personnel has become known as guest engineering (GE).

Whilst GE practice can be traced to the 1950s and the Japanese automotive industry, it was not until relatively recently that academic and practitioner publications in the West began describing the existence and benefits of GE. The actual rate of adoption of the practice varies considerably, however. For example, within the automotive sector it is clear that Japanese companies are much more active. Toyota engages approximately 5 design engineers per supplier and Nissan approximately 2 per supplier, whilst General Motors has 0.2 guest design engineers per supplier (Dyer, 1996). As an illustration of scale, Toyota has almost 350 guest design engineers at its main technical center in Japan (Dyer and Ouchi, 1993).

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# H

**healthcare operations**

*Paul Walley*

The provision of advanced health related services is both expensive – the health economy can easily consume 10 percent of a developed country's GDP – and politically challenging: in the US, for instance, spiraling healthcare costs coincide with political and societal concerns over quality and equity. For example, it appears that these initiatives need a careful focus so that the objectives are not too broad and the change is not being implemented across an unnecessarily large, complex healthcare system. Given such a context, it is therefore surprising to discover that the healthcare sector is one of the least developed in terms of its adoption of modern operations management (OM) methods. In many countries, structural issues concerning the ownership of facilities and the funding of activities may be a very significant factor. In the US, for example, many physicians work as single practices and skills are rarely pooled. This limits the extent to which a system can optimize its ability to care for patients and also leads to a poorly coordinated health supply chain. Despite such obstacles, there is a growing international movement for more effective healthcare OM. For instance, the Boston based Institute for Healthcare Improvement (IHI) is actively promoting improvement "collaboratives" as a method of implementing employee driven quality and process improvement. The work has been adapted from Deming's use of improvement cycles and translated into terminology more suitable for use in health care: improvement projects are termed "PDSA" (plan do study act) rather than "PDCA" (plan do check act; *see* DEMING; PDCA CYCLE). Like TOTAL QUALITY MANAGEMENT (TQM) initiatives in other sectors, collaborative initiatives are difficult to implement, with a range of factors that affect their degree of success (Arndt and Bigelow, 1995; Ovretveit, 2000; Jackson, 2001). For example, it appears that these initiatives need a careful focus so that the objectives are not too broad and the change is not being implemented across an unnecessarily large, complex healthcare system. Key OM themes that have emerged from these and other initiatives are described below.

## Capacity, Demand, and Queues

The lack of pooling of resources in the US healthcare system and the use of ring fenced resources in other healthcare processes has tended to encourage the formation of queues within the system. There is also growing evidence that capacity and demand variation is badly controlled, due to poor understanding of queuing theory (*see* QUEUING ANALYSIS) and the effects of variation on the system. It is unfortunate that a response to the formation of queues within the system encourages additional "triage," i.e., dividing demand based on urgency, thus splitting queues further, which adds to the problem rather than solving it. A high proportion of existing improvement activity in the UK, US, and elsewhere is focusing on stabilizing elective schedules and obtaining greater control over discharge processes to bring demand and availability of resources closer together. Some approaches, notably that of the Kaiser Permanente organization, have deliberately attempted to create economies of scale, to integrate delivery systems, and to create a more patient focused approach to healthcare. This has yielded some significant results (Feachem, Sekhri, and White, 2002). For example, it is believed that Kaiser achieves comparable or better quality of outcomes for patients with far less patient hospitalization when compared with the UK's National Health Service (Ham et al., 2003). This has been achieved through better integration of processes, active management of patients, a different emphasis of roles within the supply chain, and greater self care.

Work in this area is being deployed in the UK in conjunction with theories of group technology and cellular layout (*see* CELL LAYOUT). Demand is being grouped into process "streams" that fit comfortably with process based views of how healthcare should be segmented. This allows processes to be designed around groups or "families" of patients that follow similar treatment sequences or technologies, allowing the system design to be improved. It is acknowledged that this approach needs to carefully balance the benefits of process improvement against the capacity loss created by streaming due to lack of demand pooling. The UK's widespread adoption of "see and treat" minor patient treatment cells in emergency departments is a good example of how this approach has worked. Some departments have reduced waiting times by 90 percent as a consequence of its introduction – at little or no cost increase. Issues of employee FLEXIBILITY and job demarcation have emerged during implementation.

### Statistical Process Control

Collaborative groups are increasingly finding that statistical process control (SPC) is a valuable tool for monitoring and controlling healthcare processes. Examples would include the monitoring of rates of caesarian section, so that obstetricians can be assessed for over use of the procedure. It has been used as a measurement tool for PDSA experiments and has advantages over conventional methods of assessment, such as clinical audit, because it is faster and frequently more sensitive in its detection of changes in the performance of processes. In the UK, SPC is being used within collaborative initiatives as a means of determining process capability in meeting performance targets imposed by government authorities.

### Process Choice

A common criticism of western manufacturing industry during the 1980s was that managers were reluctant to make the switch from batch to mass or flow processes. It can be argued that the healthcare operations have exhibited the same reluctance as manufacturing companies to adapt their process choice over time. As the scale of health services has expanded, the system's design has not radically changed and is still organized to treat relatively small numbers of each patient type: a process designed to adapt itself to almost unique patients now appears to be a poorly standardized system for the higher numbers of patients requiring similar treatments. It is very easy to view the typical general hospital as a service shop – the equivalent of a batch manufacturing system. Most hospitals move patients from one department to another in complex, long distance, stop start flow patterns. In such a system, the scheduling and progressing of patients is extremely difficult. Capacity BOTTLENECKS move, making high utilization of resources near impossible. Interestingly, the few widely known systems that utilize flow processes in healthcare provision have emerged in (resource constrained) economies where the widespread availability of simple treatments (e.g., cataract surgery) was the primary objective.

### Focus in Healthcare

It is easy to view most general hospitals as unfocused facilities, with irreconcilable sets of contradictory performance objectives and organization priorities: emergency departments clearly have different (and more difficult) targets for speed and flexibility, when compared to many forms of elective treatment. The parts of the system where emergency and elective treatment processes merge are often poorly coordinated. The North American health system has experimented with focused facilities. The most widely known application is seen at the Canadian hernia repair center, Shouldice Hospital (Heskett, 1993; Gummesson, 2001). The hospital treats non smoking patients who are not overweight for their inguinal hernias. Historically, they have claimed a reoccurrence rate one tenth that of conventional methods, at a fraction of the normal cost. The design is ruthlessly based around the needs of one type of patient. Patients are encouraged to be ambulatory – they walk to the operating theater and are expected to climb off the operating table afterwards. The self service restaurant is upstairs, with steps half the normal height to accommodate patients who have been treated just two hours previously.

Focus has also been successfully applied to US "surgicenters" (Vaughan and Aluise, 1992) and has been shown to make a considerable difference to the performance of the treatment process. The decision is controversial, with clin icians who have still to be convinced that focus improves the healthcare system as a whole rather than simply improving treatment for those who qualify to enter a focused facility. Where focus has been applied more extensively, it has tended to filter patients with fewer complications, who need simpler treatment procedures, leaving a pool of more complex demand that need treat ment in "unfocused" facilities. It has high lighted the degree of cross subsidy in private healthcare systems.

### Lean Production

Lean thinking is also regarded as suitable for healthcare applications (Bowen and Youngdahl, 1998). The UK NHS Modernization Agency, for example, is promoting elements of JUST IN TIME (JIT) and lean thinking as a philoso phy that can help to reduce in process waiting through the reduction of (patient) work in pro gress. Bottlenecks are also being tackled using optimized production technology (OPT). There are lean thinking examples in US primary care (Bushell and Shelest, 2002). JIT is being used for healthcare material management (e.g., Heinbuch, 1995).

OM theory has now been successfully trans ferred into many service sector applications and there is growing application within healthcare operations. Additional use of capacity and demand theory, coupled with the use of SPC as a monitoring and control tool, is seen as neces sary to solve some of the flow problems within healthcare systems. The emphasis on quality, from the work of Deming and others, has a resonance with many clinicians, who have fre quently been concerned about the application of "factory management" to healthcare.

See also *ethics in operations management; focus; lean production; service processes; service technology*

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## hierarchy of operations

*Nigel Slack*

A key element of the operations management (OM) TRANSFORMATION MODEL is its ap plicability to very different levels of analysis. In other words, very precisely and very broadly defined parts of an operation can be viewed as part of an interconnecting hierarchy of trans formation models (e.g., factory–production line–machine group–loading/unloading pro cess). The total operation is sometimes termed a macro operation, while its "departments" are termed micro operations. These micro oper ations have inputs, some of which will come from outside the macro operation but many of which will be supplied from other internal micro operations, giving rise to the notion of internal supply chains. Similarly, each micro operation will produce outputs of goods and services for the benefit of customers, though again, some of each micro operation's custom ers will be other micro operations. Closely re lated to but conceptually extending the simple structural hierarchy of micro and macro oper ations is the systems theory based idea of emer gent properties: emergence is predicated on the observation that each level in a systems hier archy tends to possess properties that cannot be found at lower levels in the hierarchy. Put another way, the total operation is much more than the sum of its parts. The practical impli cation of this idea is that for an operation to perform to its full potential, the activities of the operation as a whole must be considered at some point.

See also *business process redesign; continuous im provement; operations management*

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## high-involvement innovation

*John Bessant*

Much has been written about the need for or ganizational learning (Argyris and Schon, 1970; Senge, 1990): in other words, the need for or ganizations to manage in more active fashion their knowledge accumulation and deployment processes and consequently to focus on if and how they learn. Within this wide ranging dis cussion there has been consideration of the use that can be made of problem finding and prob lem solving cycles (such as those used in CON TINUOUS IMPROVEMENT/*kaizen* systems), which appear to offer powerful mechanisms for building a culture of continuous innovation. The advantages of such an approach to innovation include:

- More ideas from more people: When the answer to a problem facing a firm is un known, it helps to have as many ideas and as many different lines of thinking as possible.
- Cross functional and cross disciplinary thinking: Sometimes the best solutions emerge from bringing together very differ ent perspectives.
- Mobilization of tacit knowledge: Most of what an organization knows (and could use to competitive advantage) is not written down or stored in databases but exists in the heads and fingertips of its people – they know how and when to use it even if they can't articulate it.
- Commitment to implementing change: People are more likely to accept and further develop changes that they have been in volved in creating.

Evidence suggests that organizations develop high involvement innovation over time and move from relatively simple and occasional at tempts to capture employee suggestions through to more systematic approaches that deploy mechanisms for managing the flow of ideas created, providing reward and recognition systems, linking improvement activities to monitoring and measurement systems, and, in more developed examples, connecting the over all company strategy to continuous improve ment activity through a process known as "policy deployment." In making this journey, organizations can draw on a number of enabling resources including various training inputs and specific tools and techniques (many of which were developed as part of the total quality move ment; *see* QUALITY TOOLS; TOTAL QUALITY MANAGEMENT).

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## history of operations management

*Michael Lewis and Henrique Correa*

Operations management (OM) is primarily con cerned with, and indeed regularly rededicates itself to, the immediate needs of industrial prac tice. Whilst this focus on current relevance is entirely laudable, it may have obscured the im portance of more historical perspectives: after all, even a cursory examination of the history of business thought highlights the significance of works concerned primarily with managing the act of production (Smith, 1776; Babbage, 1832; Taylor, 1911; Ford, 1922, 1926). This is a logical development because volume manufacturing, built upon the principle of DIVISION OF LABOR and the application of dedicated machin ery to specific tasks, necessitated the creation of "operations" managers removed by organiza tional hierarchy from direct productive activity. Problematically for this entry, however interest ing the antecedents of modern OM, the very fact that they stretch back to the earliest stages of industrial development (many would argue they go even further back to, for instance, the con struction of the great pyramids) means that de lineating a simple history will always be challenging and, by necessity, a simplification.

### From the UK Industrial Revolution to the American System of Manufacture

Although many histories refer to the writings of Daniel Defoe (especially with reference to the systematic management of projects), the earliest recognizably OM related ideas emerged in the UK at about the time of the industrial "revolu tion" that began in the textile industry during the eighteenth century (Landes, 1999), stimu lated by coincidental geopolitical (a rapidly growing empire, centered around India) and technological events (in particular James Watt's invention of the steam engine and other celebrated manufacturing inventions such as James Hargreaves's spinning jenny). By the mid nineteenth century, however, an alternative system of manufacturing had emerged/was emerging in America (Rosenberg, 1969; Wilson, 1998). In 1798, the US govern ment awarded Eli Whitney a contract to pro duce 10,000 muskets over a two year period. Whitney knew that he did not have enough employees to produce 10,000 muskets using traditional artisan methods and so was forced to develop machine tools. This development in turn delivered far more consistent dimensional accuracy than previously possible and allowed for the assembly of interchangeable compon ents (a version of this system had first been seen in the Arsenal of Venice in the fifteenth century) that had been produced separately. The OM task in such an organization was no longer one of coordinating the efforts of indi vidual artisans, but rather the technical prob lem of managing processes. Interchangeable parts allowed manufacturers to break more fun damentally with the craft model of production and thereby fully exploit the division of labor. Eli Whitney's approach influenced entrepre neurs in a range of other industries: Isaac Singer in the sewing machine sector, Samuel Colt in light firearms, and Henry Leland (who worked for many years in Colt's gun factory) in the nascent automobile industry. At the same time, unhindered by long established forms of organizational "focus" (embodied in structures such as craft guilds) and supported by the growth of a nationwide distribution and com munications network (i.e., the railroad), the American system moved toward the more ver tically integrated, and larger scale, production of components and raw materials – in particular steel. Later, Frederick Taylor would begin his working life and conduct his early experiments in SCIENTIFIC MANAGEMENT in the steel industry.

### Henry Ford and Frederick Taylor

The emergence of the US as the preeminent industrial power of the twentieth century can be understood through the biographies of two key personalities: Henry Ford and Frederick W. Taylor. Both men are (in)famous and have proved to be highly influential in the development of operations management. Henry Ford's objective was to make the car a product accessible to the average American and knew that in order to achieve this goal he had to significantly reduce his costs. In 1908, Henry Ford announced the birth of his "Model T." Essentially the Ford Motor Company's only product for nearly 20 years, the demand for the vehicle surpassed even Ford's most optimistic dreams. Henry Ford built his factories upon the basic American manufacturing principles but was the first to produce very complex products. In addition to his extraordinary attention to the detailed design and control of various production processes, he understood the more strategic financial and operational significance of cycle time and throughput in manufacturing. A key Ford development was the "moving assembling line" (1913), inspired by the disassembly processes of the Chicago abattoirs. By 1925, Ford was producing around 2 million cars per annum. It can be convincingly argued that it was Taylor who first "generated the sustained interest, active following and systematic framework necessary to plausibly proclaim management as a discipline" (Hopp and Spearman, 1995: 27), and many scientific management principles are now cornerstones of OM theory and practice. Always an extremely controversial figure, his philosophy was/is widely caricatured and reviled ("Taylorist!"), but many of the principles he espoused are now widely accepted. It is also interesting to note that many of Taylor's "disciples" (Barth, Gantt, the Gilbreths) helped to disseminate his ideas to prewar Japanese industry (e.g., shipbuilding), and Ford's ideas have been cited as strongly influential in the development of Japanese production systems (Ohno, 1988).

### The Emergence of Modern (Western) OM Research and Education

As all types of organization grew in scale and scope, there followed the emergence of an increasingly professional managerial class dedicated to controlling ever more complicated operating systems. By the turn of the twentieth century this had created, in North America in particular, a marketplace for operations (scientific) management education and techniques: in 1913, for example, F. W. Harris (an engineer working for Westinghouse) developed an analytic model of the ECONOMIC ORDER QUANTITY (EOQ); mathematician A. K. Erlang (1878–1929) began to develop the fundamentals of queuing theory (*see* QUEUING ANALYSIS); and Walter A. Shewart (working at Bell Telephone Laboratories) began to develop the fundamentals of what would become statistical process control. At about the same time, engineering education was broadening to include industrial engineering courses, also strongly influenced by scientific management principles. By the 1950s, the scope of OM as a descriptive field (i.e., "this is industrial management") had become very broad (including personnel management, accounts, general management, etc.). Buffa (1982) argues that this meant that as curricula were "dismantled and differentiated into the several functional fields," this left the parent OM discipline with "a nearly empty basket of techniques" and almost no underlying research direction. As a result, the field began to incorporate operations research techniques, which had proved themselves extremely valuable during World War II (McCloskey, 1987) and seemed to offer OM a suitably scientific (quantitative) way forward. This relationship between OM and operations research/management science (OR/MS) has been and remains extremely close: consider core techniques for managing large projects such as PERT (program evaluation and review technique), developed to help the US Navy develop the Polaris missile, or CPM (critical path method), developed by DuPont for instance. That said, it is not entirely without its problems. The increased emphasis in OM research on "defining a problem . . . building a model to represent it and evaluating the results by a single valued criterion," or building "more complex models [which] we presume are more realistic, since they take into account more variables," can be viewed as having taken the discipline away from "dealing with the broader managerial implications of decisions in production systems" (Buffa, 1982).

Western OM throughout most of the twentieth century focused on issues of production planning and control: determining the performance impact (in terms of cost, quality, speed, etc.) of decisions about how long something will take to produce; how many things to produce at a time; in what order to produce them, following what route through the operation, and so on. Taylor's early work focused on developing tools to measure work and working practices, thus allowing managers to compare the performance of individuals and thereby increase PRODUCTIVITY by exerting greater control. Over time, especially with the introduction of OR/MS methods, a much wider range of models was developed and applied to an ever greater range of operations related problems.

Ultimately, however, the practical influence of these methods was relatively limited until computerized production and INVENTORY CONTROL SYSTEMS were able to apply them in a rapid and efficient manner. As operations grew ever more complex, the focus of SCHEDULING research increasingly shifted to these computer based solutions for scheduling. Unsurprisingly perhaps, IBM was one of the first firms to study and apply the methods. It was while working for the "Big Blue" that Joseph Orlicky and colleagues first developed what became known as MATERIAL REQUIREMENTS PLANNING (MRP). MRP uses the "Bill of Material as the basis for planning" (Orlicky, Plossl, and Wight, 1972; *see* BILL OF MATERIALS) because the demand for most components (dependent) is actually a function of demand for the final product (independent) and therefore known given a reasonably stable overall production schedule. MRP has evolved over time into MANUFACTURING RESOURCES PLANNING (MRPII) as it has integrated decision criteria from other functional areas (sales, staffing, etc.). One interesting contribution to this evolution was the development of OPTIMIZED PRODUCTION TECHNOLOGY (OPT), derived from the work of Eliyahu Goldratt. In his bestselling management novel *The Goal* (Goldratt and Cox, 1984), the protagonist (a much put upon operations manager) learns the benefits of strategic FOCUS and of focusing on factory BOTTLENECKS. Linked to this logic, OPT is essentially a variation of MRP that combines the bill of materials with a routing file that can identify and prioritize (using a "secret" algorithm) all parts movement through bottlenecks.

### The Japanization of OM

While MRP and its various derivatives were the subject of western academic and practitioner OM interest, Japanese industrial development (especially in the automotive industry) was following a very different "control" trajectory (Sugimori et al., 1977). The embodiment of this different philosophy was the Toyota production system (TPS), which can be summarized as an adherence to two key principles. The first of these is an emphasis on planning and control driven by customer pull rather than organization push. Such systems seek to prioritize work in progress (WIP) reduction over capacity utilization (compare this with a classic line balance approach; *see* LINE BALANCING) and are enabled by (and/or necessitate) production smoothing, quick setup times (*see* SETUP REDUCTION), and stages closely interconnected by *kanbans* (*see* KANBAN).

The second key principle is a commitment to CONTINUOUS IMPROVEMENT enabled by people development. The practical implementation of this apparently straightforward principle is much more challenging.

It was analysis of the TPS and its derivatives that led to what has become the quintessential OM work of the last 20 years: the INTERNATIONAL MOTOR VEHICLE PROGRAM (IMVP) report into the performance of the global motor industry (Womack, Jones, and Roos, 1990). This study "revealed" the existence of a 2 : 1 difference in productivity between car assembly plants in Japan and those in the West. The performance differential was ascribed to TPS or LEAN PRODUCTION practices that improved productivity through reduced lead times, material and staff costs, increased QUALITY, etc. These findings led to a great deal of automotive industry "soul searching" and, perhaps inevitably, further BENCHMARKING studies which appeared to confirm the initial IMVP results. Given such a backdrop, it is unsurprising that lean production practices aroused such intense interest. Enhanced productivity has universal appeal, regardless of whether it is Toyota seeking to survive the oil price shock of 1972–3 or any western manufacturer faced with increasingly intensive global competition. Indeed, lean production's originators, by formulating the "operating problem" as an unceasing battle against waste (or *muda* in Japanese), were able to make it seem almost axiomatic that lean implied better. Although the lean production concept was initially viewed as a counter intuitive alternative to traditional manufacturing models, today it is arguably *the* paradigm for manufacturing operations (Krafcik, 1988).

### Service and Strategy

Given its heritage, it is perhaps unsurprising to discover that OM has developed with an almost exclusive manufacturing focus. The growth of a "service imperative" has begun to change this, under the influence of what Johnston (1994) argues are two key factors. The first of these is strategic, in other words the "recognition that service, how the goods are delivered to the customer and how the customer is treated, provides many manufacturing organizations with a competitive edge." The second reason is more pragmatic: the recognition that manufacturing accounts for a smaller and smaller proportion of GDP in most western economies. Early contributions to the service literature sought to directly apply manufacturing concepts to service contexts (e.g., McDonald's), but traditional OM lacked any conceptualization of transactions directly involving the customer. Specific developments that together characterize SERVICE OPERATIONS include the definition and analysis of "front" and "back" office operations, while other works have explored the interactive nature (i.e., customers can be asked to do some of the work) of service productivity.

One of Johnston's (1994) explanations for the growing significance of service OM was what he called the strategic imperative or the broadening of OM interests beyond narrow notions of internal efficiency. Following Skinner's (1969) early "call to arms" (Harvard's production and operations management faculty had been interested in strategy since the early 1960s), the initial focus was on the process and content of MANUFACTURING STRATEGY. Over time, this has broadened to OPERATIONS STRATEGY. Academic and industrial interest in the strategic management of operations has paralleled the growth of interest in resource or capability based alternatives to the dominant positional model of competitive strategy. The overlaps are often explicit: Prahalad and Hamel (1990), for example, defined their "core competencies" as "collective learning . . . especially how to coordinate diverse production skills and integrate multiple streams of technologies." Although the "outside in" view of strategy argues that the only strategic role of operations is to support the firm's broader strategic goals, there is a growing body of operations strategy literature that seeks to incorporate a resource/capability perspective. Interestingly, resource/capability theory offers an implicit yet powerful critique of much of the descriptive OM research directed toward establishing BEST PRACTICE. If it is the *unique* aspects of an organization that create long lasting advantage, the suggestion that factors *common* to several firms can be true sources of success is at least somewhat problematic.

### Concluding Comments

Given this overview of OM's history, it is sensible to conclude that many of the forces that have shaped its development over the last two centuries will continue to shape its future. There will be some "voices" that emphasize conceptual rigor and the development of scientific insight, whereas others (and market forces) will express concerns over a drift away from practical relevance, and a call to reestablish the discipline using practitioner "needs" as a guide (Hayes, 2000). In the short/medium term, it seems likely that more integrative and strategic themes will continue to grow in significance and OM will continue to explore more intangible service operations, a trend accentuated by market (i.e., student and practitioner) demands for more strategic and service exemplars (and fewer quantitative studies).

See also *operations management*

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## Human-centered CIM

*Felix Schmid*

The "techno centric" tendencies of early computer integrated manufacturing (CIM) greatly constrained the role of the human operators but did not lead to the expected efficiencies. The concept of a human centric (or anthropocentric) approach to CIM was formulated by Howard Rosenbrock in the early 1980s, in response to the failure of the technology focused approach. In general terms, a human centered technology is one that supports the application of human skill to manufacturing and maintenance situations and that enhances the performance of people carrying out their tasks. Technologies should thus be designed to optimize the synergy between human skill and computer power. Work within a factory or business unit should be organized in such a way that employees at all levels of a hierarchy are able to apply a substantial range of their skills rather than just a small, "locally useful" part. To achieve this, individual skill and competence must be increased through a balanced combination of learning by doing and formal training and education. The suggested benefits for a human centered system include: greater utilization of design and manufacturing skills; greater FLEXIBILITY, derived from an enhanced range of operator responsibilities (e.g., production work as well as quality and planning related duties), and improved QUALITY as each employee develops a general knowledge of the whole production process. Organization structures must be adapted to allow staff the opportunities and freedom to contribute to all relevant aspects of the operation.

*See also* computer integrated manufacturing

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# I

## implementing process technology

*Michael Lewis*

Successfully implementing process technology is, like any significant technical/organizational change, actually very difficult and involves much more than "simple" adherence to a plan. A great deal of operations management (OM) research has sought to identify the ingredients of a suc cessful implementation and, in addition to a whole set of project/organization specific issues, these findings can be summarized under three linked categories. First, an understanding of the technology's characteristics is crucial – especially given the breadth of "technologies which primarily utilize computers to control, track or monitor manufacturing activities, either directly or indirectly." Second, many studies suggested that process technologies are often viewed as having failed to yield potential benefits because the implementation was not aligned to overall strategic goals. Third, the absence of implementation success has been ascribed to failing to consider compatibility with existing systems, organizational structures, and even at titudes and values or to invest in the organiza tional infrastructure that will support the new technology.

### Technological Factors

Definitions of process technology include appli cations that both "directly" produce products (e.g., robots welding on a production line; *see* ROBOTICS) and others acting to "support" these activities (e.g., enterprise resource plan ning systems, route planning, and staff roster software). Most core OM typologies describe the influence of different direct process technol ogy choices. Such a breadth of application en compasses a wide variety of different functional technologies but, increasingly, all comprise sub stantial information technology (IT) compon ents. IT is not intrinsically more difficult to implement than other forms of technology but it can create greater levels of uncertainty in the implementation process and IT rich solutions commonly require additional process changes and different skill requirements.

In addition to typologies illustrating technol ogy types (e.g., PRODUCT–PROCESS MATRIX), the literature highlights examples of the factors – such as component incompatibility – that can influence likely implementation success. For example, any given technology's transferability and divisibility characteristics will directly influ ence its "implementability." Transferability is a composite of the extent to which developers are still engaged in basic problem solving activities and, correspondingly, the degree to which a tech nology's operating and underlying scientific principles are communicable to people other than its developers. Divisibility is the degree to which the technology can be partitioned to allow trial adoption, thus providing the parent organ ization with an abandonment option. It is there fore an important characteristic that should be cultivated and then exploited.

### Strategic Factors

Just as Hill's (1994) influential manufacturing strategy methodology clarifies market ORDER WINNERS AND QUALIFIERS before moving on to discuss technological infrastructure, there are repeated calls in the process technology lit erature for implementation to be based upon a market driven approach to competitive benefits that follows broader corporate or manufacturing strategy priorities. Of course, underneath such conceptual simplicity lies the problematic process of translating requirements into organizational and technical specifications. Correspondingly, many studies emphasize how the system must be of major importance to top management's objective for the business. The absence of this factor is probably the single most commonly cited reason for lack of implementation success. This in turn suggests a number of specific characteristics that will insure such political support: benefits (e.g., cost savings) must be measurable, demonstrable, and substantial if they are to receive the necessary support and resources from top management (Burcher, Lee, and Sohal, 1999).

Organizational Factors

The benefits of process technology are dependent upon both altering the technology to fit the organization and simultaneously shaping the user environment to exploit the potential of the technology. There is some argument that if any new technology is used with existing operational processes it will prove to be expensive and ineffective, but at the same time the greater the span (i.e., people affected) and scope (i.e., organizational subunits altering outputs or inputs) of the technology, the more challenging the implementation is likely to be. As a specific response to this managerial dilemma, researchers have argued for giving workers more autonomy and control over "their" processes (i.e., semi autonomous groups) so that, when married to increased levels of skills training, they can respond flexibly and effectively to the changes introduced by new process technology. All too often, managers view implementation as a technical problem to be solved by process engineers, who in general have only a narrow understanding of the organizational implications. Likewise, the need to emphasize regular and rich communication within and between functions and work groups is a key component of the organizational learning needed to introduce new technology to any "shop floor." Another recurring organizational factor relates to the difficulty of quantifying both the benefits and implementation costs of process technology. Benefits can be medium or long term and strategic in nature, whilst there are also often hidden costs related to, for example, short term PRODUCTIVITY dips and training. Taken together, this may necessitate changes to PERFORMANCE MEASUREMENT and investment appraisal systems. In turn, this implies that some types of project (e.g., complex, leading edge applications) will require a sponsor or champion of sufficient seniority to authorize the needed capital investments and to make necessary changes in the relevant reward systems. Overall, the most consistently highlighted factor is the strong support of top management: indeed, a significant amount of the OM process technology literature is devoted to research concerning manager–project leader relationships.

See also *advanced manufacturing technology; enterprise resources planning; manufacturing strategy; operations strategy; process technology; project management*

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## importance performance matrix

*Nigel Slack*

One of the most significant activities in the operations strategy formulation process is the derivation of a list of competitive factors prioritized in terms of their relative importance. Typically, such a list ranks or rates those factors that the operations function contributes to the competitiveness of the organization. So, for example, QUALITY may be regarded as more important than product or service range but less so than price, and so on. Process of manufacturing strategy formulation models may also include an attempt to assess the operations performance against its competitors (*see* MANUFACTURING STRATEGY). This allows the gap between relative importance and performance to be compared in order to prioritize improvement efforts.

In the SERVICE OPERATIONS/marketing area one gap based method is that proposed by Martilla and James (1977), who suggested an importance–performance matrix. The utility of such a matrix lies in its ability to bring together both customers (importance) and competitor (performance) perspectives to judging the relative improvement priorities that need to be applied to competitive criteria. One suggested form of the matrix (Slack, 1994) is divided into zones representing different improvement priorities. There is a "lower boundary of acceptability," representing the boundary between acceptable and unacceptable performance relative to importance. Below this line there is a need for improvement: above it there is no immediate urgency for any improvement. However, not all competitive factors falling below the minimum line have the same degree of improvement priority. A further boundary represents a distinction between an urgent priority zone and a less urgent improvement zone. Similarly, above the "lower boundary of acceptability," not all competitive factors are regarded as having the same characteristics and a further boundary is defined between performance levels that were regarded as "good" or "appropriate" on the one hand, and those regarded as "too good" or "excess" on the other. Segregating the matrix in this way results in four zones that imply different treatments.

The "appropriate" zone is bounded on its lower edge by the "minimum performance boundary," i.e., the level of performance below which the company, in the medium term, would not wish the operation to fall. Moving performance up to, or above, this boundary is likely to be the first stage objective for any improvement program. Competitive factors that fall in this area should be considered satisfactory, at least in the short to medium term. Any competitive factor that lies below the lower bound of the "appropriate" zone will be a candidate for improvement. Those lying either just below the bound or in the bottom left hand corner of the matrix (where performance is poor but it matters less) are likely to be viewed as non urgent cases. They need improving, but probably not as a first priority. This is the "improve" zone.

More critical will be any competitive factor that lies in the "urgent action" zone. These are aspects of operations performance where achievement is so far below what it ought to be, given its importance to the customer, that business is probably being lost directly as a result. The short term objective must therefore be to raise the performance of any competitive factors lying in this zone at least up to the "improve" zone. In the medium term they would need to be improved to beyond the lower bound of the "appropriate" zone.

The "excess?" zone lies in the top left hand area of the matrix. If any competitive factors lie in this area, their achieved performance is far better than would seem to be warranted. This does not necessarily mean that too many resources are being used to achieve such a level, but it may do. It is only sensible therefore to check whether any resources that have been used to achieve such a performance could be diverted to a more needy factor.

See also *operations objectives; operations strategy; order winners and qualifiers; performance measurement*

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**industrial engineering**

*Michael Gregory*

Industrial engineering is a discipline that is concerned with increasing the effectiveness of (primarily) manufacturing and (occasionally) SERVICE OPERATIONS. Although much of the content of the discipline overlaps with oper ations management – indeed, it shares roots with operations management in the scientific management movement of the early twentieth century (*see* HISTORY OF OPERATIONS MAN AGEMENT) – it has traditionally had a more precisely defined, operational and technological focus.

See also *manufacturing systems engineering; oper ations management; scientific management*

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**industrial networks**

*Christer Karlsson*

The industrial network perspective has three basic building blocks: actors, resources, and ac tivities. These are related to each other in the following way.

- Actors have knowledge of resources and con trol them.
- Actors have knowledge of activities and per form them.
- Activities change or exchange resources.
- Actors exist on all levels from individuals to companies.
- Resources include human, physical, and financial.
- Activities include transformations and trans actions.
- The three building blocks and their relations constitute the network.

BACKGROUND

Companies organize in a way that involves many activities that are external to the traditional organizational boundaries, and as a consequence managing operations involves many issues and actions dealing with external networks. This presents challenges when managing networks of operations. This perspective may be called managing an "extraprise" rather than an "enter prise." It is important therefore to analyze what industrial network development and externaliza tion of operations activities means for manage ment of operations. It should be noted that "an industrial network" should not be seen as an organizational form but as a perspective that can be used to enrich one's understanding of organizations.

THE TECHNOLOGY KNOWLEDGE NETWORK

External sourcing organizations come in many variants. There are different types of organiza tions with different roles and relations located both vertically and horizontally to any organiza tion. Typically, vertically there are suppliers at different tiers in a hierarchy of systems sup pliers, subsystem suppliers, and component suppliers. Some lower tier suppliers may deliver directly to the original equipment manufacturer (OEM). There are also suppliers in the form of "integrators," so called because they integrate components and systems from different sup pliers normally into bigger physical units but do not add any particular own technology. Ver tically there are also many holders of specific knowledge such as consultants and educational ventures. Similarly, there are horizontal part ners, joint ventures, and other manufacturers in the industry. There may be capital ventures as investment in emerging technologies and also internal ventures established as autonomous companies. Together, all these organizational units form a complex network.

The combination of the internal organization and all the external units forms a network that not only is complex in structure, forms of rela tions, and LOGISTICS, but also demonstrates how little of the total product development and production may take place within the company itself. A large proportion of not only manufac turing but also product and even concept devel opment may take place outside the traditional organization (*see* NEW PRODUCT DEVELOP MENT PROCESS). It is not uncommon for this external development to be 70–80 percent of

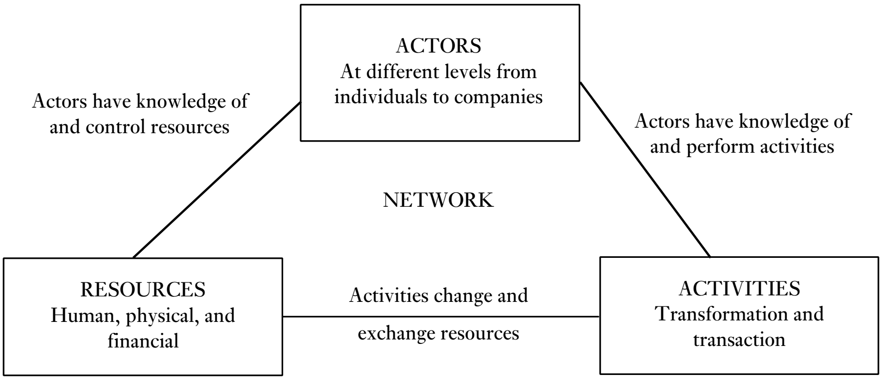


**Figure 1** The network perspective

total development efforts (in money or time). It is obvious, then, that the attention of both top management and many other managers must be devoted to managing activities in the whole net work. Therefore, the strategically most import ant unit of management and analysis is the network, not the internal organization. Further more, there is not only one but many networks to manage since the organization may form and be involved in different networks in different parts of its activities.

There are many ways in which operations management is and will continue to be influ enced by the development of industrial net works. These are described below.

### Shifting Perspectives: The Organization in a Network Perspective

The core essence of a business is the value cre ator for the customer. Its *raison d'être* is to pro vide value for the customer by offering a function that the customer is willing to buy. The corporation is focused on developing that function through system integration. It will create the best possible demanded function by putting together the best subsystems from the best sources. The network corporation is not one company or a specific organization that has a clear boundary. Rather, the system boundary can be defined differently in different situations and for different parts of the business. In changing from a systems to a network perspec tive, different actors control different resources, perform different activities, and use different resources, with actors, resources, and activities that do not overlap fully in one organizational unit. In this perspective, the classic concept of an organization fades away. The network becomes the prime unit of management, not the company. The organization is said to be "extended," "hollow," or "virtual."

### Actors: From Individuals to Companies

Industrial companies are actors who can be expected to offer new functions and product characteristics as well as new products. This implies greater demands on operations man agers, especially in feature and systems engin eering. One measure for the OEM to take can be the actual development of navigator or agent functions that in turn can work with many re sources beyond the earlier organizational bound aries. Moreover, an increased focus on value networks (instead of value chains) can be expected when more units are interrelated. Key questions are, what value is created in each pos ition in the network, what costs are involved, and who is willing to pay how much for that? It is important to manage or at least have some con trol over the value chain all the way to the customer.

### Resources: Human, Physical, and Financial

Accepting that the undertaking of operations is to a large extent taking place through resources and activities external to the organization, the perspective of the organization will change from a closed to an open system, and to a multistruc tured body or network. Therefore, the company as an entity is less clearly defined. Potential operations resources in the network organization no longer have clear limits. The managerial unit can be said to change from the enterprise to the extraprise. That extraprise is built on the core company being the central actor in its network, together with other actors, other resources, and other activities in its network. The company will of course be involved in different networks, which will look different at different times. The makeup of the networked resources has to be continuously evaluated and frequent changes can be expected, since there is no single organ izational form with specific structure, roles, and responsibilities. This implies an almost paradigmatic shift in perspective: that of con tinuous organizing instead of there being an organization.

This task dependence may also be seen as implying that the concept of the DIVISION OF LABOR will be restored to its traditional position of importance. However, generally the focus of interest is not the division of work between workers but between productive units. Activities are ideally allocated to where they are carried through in the most effective way. Hence the importance of economy of scale is moving from the individual production unit to the global pro duction system when productive units are "focused plants" in a global set of operations. Not only production but also other functions are allocated with global considerations for division of work. Product development can be allocated where the best engineers are found and manage ment where executives like to live.

### Activities: Transformations and Transactions

A key issue in the network perspective is, then, the management of activities within the net work focused organization. Based on the litera ture covering the management of supplier relations, joint ventures, and other external ac tivities, it has been proposed that useful man agerial tools will be strategic management tools, especially those concerning such issues as stra tegic vision, objectives, goals, and policies (Karlsson, 2003).

One effect of the global network organization on relations is a move from hierarchical to market like transactions inside as well as outside the traditional organization; another is more em phasis on international transactions. Because of a higher number of market type relations, there is an increasing demand for skills in many kinds of negotiations. A higher number of international intercultural settings where the individuals are little used to one another and one another's languages will increasingly be a natural working environment.

Transformations and transactions take place not only in individual companies and dyads but in complicated networks of actors. The feel ing of belonging will then move from the own organization and its business relations to a complicated network of relations in a group of actors.

### Actors Have Knowledge of Resources and Control Them

With the corporation's task to be a value creator for the customer, the role of management is to build an organizational system that is the best possible value creator and function provider. This task of building and developing a network involves being a network boundary definer con currently with being a network developer, in ternally and externally. For each emerging network in which the actor in the form of the company is involved, the actor in the form of the manager must be the resource contractor, again externally as well as internally. The best possible resources must continuously be con tacted and negotiated. Consequently, managers will increasingly have to deal in market relations rather than with hierarchies.

### Actors Have Knowledge of Activities and Perform Them

The focus of management changes from the individual company to the global network. Man agers act in the networked organization. Differ ent activities may take place in different locations. Activities are allocated according to a global division of work concept. Management as well as unions increasingly deal with the strengths and weaknesses of the extended net work in which they are involved.

Both outside and inside the company there are market type relations with many entities. The whole organization changes in the direction of a "projectified" organization since organizational units are increasingly task contingent and tem porary. The project becomes the key actor. Eventually, there is a vision of a network with projects only.

The projectified organization requires more and more of its members to understand the whole of their specific business. A consequence is more cross functional activities with little spe cialization and an increasing need for under standing the whole business.

Another aspect of managing the network organization comes from the philosophies of sourcing. In a projectified network organ ization where each level is focusing horizontal technologies and concurrently sourcing vertical technologies, there will be a lot of sourcing. Understanding procurement and sourcing skills tends to be a must for many members of the network organization. The individual oper ator issues purchasing orders to a supplier and integrates purchasing in his/her work role (*see* PURCHASING). The product engineer buys technical development, the process engineer buys equipment, and the salesperson markets information.

### Activities Change or Exchange Resources

Specifically, the idea of technology levels leads to a kind of "black box procurement" at differ ent levels of, and different directions in, the network organization. As an effect it becomes important to develop skills in communicating characteristics of interfaces as well as integrating technologies into product features and func tions. To understand and practice these new forms of communication, hands on skills in knowledge management may be a tool.

The network organization with its many re sources and relations will have a tendency to be ever developing. Competitors, partners, sup pliers, and others inside or outside the several networks in which the company is engaged may act anywhere, anytime. Time then becomes an important competitive factor in why we need new ways of registering and assessing our utiliza tion of resources. One consequence is that we need better ways of observing how we use time.

See also *extraprise; outsourcing; supply chain coordination; supply chain management*

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## innovations in service companies

*Adegoke Oke*

The service sector in most western economies dominates economic activity, contributing be tween 78 percent and 82 percent of gross na tional product (GNP). However, the exact definition of the "service sector" is debatable, at its widest being taken as all non manufactur ing activity. Typically, the sector is assumed to comprise the transport business, government, education, healthcare, and retail/wholesale, telecommunications, and financial services, amongst others. The nature of innovation in service companies has attracted recent interest in the academic literature (see Johne and Storey, 1997; de Brentani, 2001). Nonetheless, there is no clear understanding of what constitutes innovations in service companies when compared to manufacturing companies where the concept of innovation is relatively well understood. This is probably because of the intangibility of services. For instance, while tangible products may be offered with or without customer service elements, almost all service products involve close interaction with customers. Therefore, service firms cannot rely purely on their core "product" advantage for competitive advantage.

A significant distinction is often made between "innovations in service companies" and "service innovation." There are many types of *innovation in service companies*. These include innovation in the nature of new services that improve the customer offer, innovation in the delivery of these services to customers, and innovation in either the core service or the process that delivers it to achieve improved internal costs and profitability. *Service innovation* is innovation that leads to new developments in those activities that are undertaken to deliver the core service product and make it more attractive to consumers. They always tend to involve interaction with customers.

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## innovator's dilemma

*Michael Lewis*

Simply put, the "innovator's dilemma" is when, faced by radical shifts in the technological or operating model of a product or service, long established customer needs can actually become an obstacle to rather than an enabler of change. All operations develop an inertia based upon the trajectory of previous decisions: this can have both positive and negative effects. Being strongly oriented to current customer requirements, for example, can lead to market success, but it can also expose companies when challenged by radically new products and services. It is this vulnerability that Professor Clayton Christensen of Harvard Business School has called the "innovator's dilemma" (Christensen, 1997). Consider the following example. Digital Equipment Corporation (DEC) once dominated the minicomputer market. It was renowned for understanding its customers' requirements, translating them into well received products, and developing operations to support its product/market strategy. But eventually, it was its very expertise at following its existing customers' requirements that caused it to ignore the threat from smaller and cheaper personal computers: "precisely because [DEC] listened to their customers, invested aggressively in new technologies that would provide their customers more and better products of the sort they wanted, and because they carefully studied market trends . . . , they lost their positions of leadership." In other words, "there are times at which it is right not to listen to customers."

Further developing his concept, Christensen divided technologies into sustaining and disruptive technologies. Sustaining technologies are those that improve the performance of established products and services along the same trajectory of performance that the majority of customers have historically valued. Disruptive technologies are those which, in the short term, cannot match the performance that customers expect from products and services. They are typically simpler, cheaper, smaller, and sometimes more convenient, but they do not often provide conventionally enhanced product or service characteristics. However, all technologies, sustaining or disruptive, will improve over time. Christensen's main point is that, because technology can progress faster than the requirements of the market, disruptive technologies will eventually enter the zone of performance that is acceptable to the markets. One example he uses is that of the electric car. At the moment, no electric car can come close to the performance characteristics of internal combustion engineers. In that sense, this technology is not an immedi ate threat to existing car or engine manufactur ers. However, the electric car is a disruptive technology in so far as its performance will even tually improve to the extent that it enters the lower end of the acceptable zone of performance. Perhaps initially only customers with relatively niche requirements will adopt motor vehicles using this technology. Eventually, however, it could prove to be the dominant technology for all types of vehicle. The dilemma facing all organizations is how to simultaneously im prove product or service performance based on sustaining technologies whilst deciding whether and how to incorporate disruptive technologies.

See also *new product development process; organization of development; process technology*

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## integrated management systems

*Barrie Dale*

An integrated management system (IMS) deals with separate management systems covering quality, environmental, and health and safety issues, and insures that they align with the or ganization's strategy. The design of ISO 14001, BS 8800, BSI OHSAS 18001, and ISO 9001 has been undertaken to facilitate their integration. An IMS can be defined as that part of the overall management system which includes the com bined resources, processes, and structures for planning, implementing, controlling, measur ing, improving, and auditing the combined quality, environment, and health and safety requirements of the organization (Wilkinson and Dale, in Dale, 2003: ch. 15).

Integration can be viewed in a number of different ways, from the implementation of a single system throughout the whole organiza tion, to the combining of two or more systems through similarities in their structure, to organ ization wide integration of all management systems with the policy and objectives of each system aligned to the overall policy. Wilkinson and Dale (2001) have identified three key integration issues.

1 Differences in understanding of the term integration and the two main approaches adopted – merging of the documentation through an aligned approach and implemen tation of the integrated system through a total quality management (TQM) approach – suggest that integration is taking place in two ways and at different levels. Merging of the documentation through the aligned ap proach is adequate for certification purposes, but the scope of the IMS and the level of integration will also be reflected by the organization's needs and its culture.
2 Integration into a single merged standard is not favored by standard writers and the cur rent focus of attention by the British Stand ards Institution (BSI) and the International Organization for Standardization (ISO) is on achieving compatibility between the stand ards in order to bring about their alignment. The objective is to increase understanding and to simplify the terminology used; as a result, a reduction in administration and audit costs will be possible. However, the lack of compatibility in the standards has not prevented organizations from combining their documentation, and some are looking for more than reduced audit and adminis tration costs from their IMS.
3 Differences in the scope of the systems do not hinder merging of the documentation through the aligned approach, but imple mentation of an IMS is likely to be adversely affected by these differences. This suggests that differences in scope are more impor tant than differences in terminology and definitions.

An IMS Model

The model described by Wilkinson and Dale (2001) provides a definition of an IMS which is based on existing and accepted definitions of a quality management system (QMS), environ mental management system (EMS), and occupa tional health and safety management system (OH&SMS) given in the relevant standards. It shows the elements of an IMS and what needs to be considered in its implementation. The model can be used by any organization wishing to im plement an IMS but particularly by those that have recognized and accepted the difference be tween an IMS based on the requirements of the standards and the need to exceed those require ments for full integration. Since the model is based on a TQM approach, experience in intro ducing such an initiative is likely to make imple mentation of an IMS easier.

The model shows a combined system contain ing a QMS, EMS, and OH&SMS where each of these three systems/subsystems has lost its in dependence; their outputs contribute to the final output, and the boundary of each is the same. The resources and processes and procedures interact through the organization's structure and culture to carry out the activities of plan ning, controlling, implementing, measuring, im proving, and auditing, and transform inputs into outputs. The outputs are then compared with the organization's goals, which have been deter mined by its policy and the needs of all stake holders. The results of this comparison are then fed back to the input, so that the aims and objectives can be revised and the resources adjusted, if necessary, in a sequence of activities which forms a cycle of CONTINUOUS IM PROVEMENT. The driving force in the system is leadership and the resources used are the combined resources of the QMS, EMS, and OH&SMS, which include people, finance, equipment, the tools and techniques used, infor mation and documentation, and training. Inte grating these resources helps to insure that everyone and everything used is involved with and provides an input to the combined quality, environment, and health and safety processes.

The processes used have a common scope, which is satisfying stakeholders' requirements, and a common range of activities, each of which addresses quality, environment, and health and safety needs and policy.

The resources and activities of the IMS oper ate through an integrated organizational struc ture and culture, where the structure is a common set of relationships, responsibilities, authorities, and communication channels that promotes the key elements of TQM, such as teamworking, involvement, and cooperation.

See also *quality; quality management systems; total quality management*

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## internal customer supplier relationships

*Nigel Slack*

The terms internal customer and internal sup plier can be used to describe those micro oper ations which take outputs from, and give inputs to, any other micro operations. Each micro op eration is therefore *at the same time* both an internal supplier of goods and services and an internal customer for the other micro operation's goods and services.

The internal customer–supplier concept is regarded by some as one of the most powerful aspects to emerge from TOTAL QUALITY MANAGEMENT. It is recognition that everyone is a customer within the organization and con sumes goods or services provided by other in ternal suppliers, but at the same time is an internal supplier of goods and services for other internal customers. The implication of this is that errors in the service provided within an organization will eventually affect the product or service that reaches the external customer. It follows that if external customers are to be satis fied, every part of the organization must contrib ute to external customer satisfaction by satisfying its own internal customers. This is done primarily by defining as clearly as possible what their own and their customers' *requirements* are. In effect this means defining what consti tutes "error free" service, the QUALITY, speed, dependability, and FLEXIBILITY required by internal customers. The exercise replicates what should be going on for the macro operation with its external customers.

As well as helping to embed the quality im perative in every part of the operation, the in ternal customer concept is useful because it impacts on the "upstream" parts of the internal supply network. These parts of the organization, especially those that provide internal services, can be the origin of errors that do not always become evident until later in the process.

It is generally recognized that *internal* custom ers and suppliers cannot be treated in exactly the same way as *external* customers and suppliers are treated. External customers and suppliers usu ally operate in a free market. If an organization believes that in the long run it can get a better deal by purchasing goods and services from an other supplier, it will do so. Similarly, the organ ization would not expect its customers to purchase its own goods and services unless it could in some way offer a better deal than its competitors. Internal customers and suppliers, however, cannot operate like this. They are not (in the short term) in a "free market" and they usually cannot look outside to either purchase input resources or sell their output goods and services.

However, notwithstanding the differences be tween internal and external customers, the con cept is useful in the sense that it provides a model to analyze the internal activities of an operation. If the macro operation is not working as it should, the error can be traced back along the internal network of customers and suppliers.

Some organizations bring a degree of formal ity to the internal customer concept by encour aging (or requiring) different parts of the operation to agree "service level agreements" (SLAs) with one another. SLAs are formal def initions of the dimensions of service and the relationship between two parts of an organiza tion. The type of issues that would be covered by such an agreement could include response times, the range of services, dependability of service supply, and so on. Boundaries of responsibility and appropriate performance measures could also be agreed (*see* PERFORMANCE MEASURE MENT).

Criticisms of the concept largely center on its implicit acceptance of the existing organizational structure of an organization. By contrast, ap proaches such as BUSINESS PROCESS RE DESIGN take a more radical stance that would be difficult using the internal customer–supplier concept.

See also *service quality*

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## international location

*David Bennett*

The international location decision is one that is concerned with the location of facilities at the highest level. It is a decision that needs to be made by any organization involved in international operations. Such organizations can include subsidiaries of multinational enter prises, international joint ventures, licensees, or franchising operations. They may be involved in a range of different activities such as local assembly, offshore manufacturing, or the com plete production of goods for global markets. International organizations are also increasingly becoming involved in the delivery of services, particularly since the barriers preventing them being transferred across national boundaries are progressively being removed.

In many respects the international location decision is similar to any decision regarding the location of facilities for a domestic organization. Tangible factors can be taken into account, such as the cost of land, cost of buildings, labor costs, transport costs, and so on. Similarly, there are intangible factors to be considered, such as en vironmental constraints and ease of communi cations.

Perhaps the main thing that distinguishes an international location decision from a domestic one is its strategic dimension. Many organiza tions choose a particular international location with a view to exploiting the long term possibil ities offered and not simply to meet short term objectives. Therefore, many of the established techniques for evaluating alternative locations or determining an "optimum" location are only of partial relevance.

The actual method used to determine the location of an international operation will tend to vary according to its type.

Local assembly normally takes place where tariff barriers exist on imported goods, or the assembly costs in the parent company are high, thereby making the products too expensive in the local market. The solution is therefore to use local labor to assemble CKD (complete knock down) or SKD (semi knockdown) kits, thereby avoiding import tariffs or taking advantage of lower local labor costs. Location decisions in this case need to consider the LOGISTICS of supplying parts and the availability of suitable low cost labor.

Offshore manufacturing is where products are made in a foreign country to the design of, and often using parts supplied by, an original equip ment manufacturer (OEM), then reexported to the country of the OEM or to third countries. Therefore it is often restricted to assembly oper ations with the purpose of exploiting one or more of the local advantages such as reduced labor costs, specialized skills, or lower over heads. Where there is a tariff on imported ma terials, this is often overcome by locating in an "export processing zone," which is a tariff free area for export oriented companies. Location decisions in such situations are influenced by the local costs of production, the incentive and taxation regime, and the ease with which mater ials, parts, and finished goods can be transported into and out of the country in question.

Complete production of goods for the global market is the approach to international oper ations commonly encountered in multinational corporations. It is often chosen because it offers the opportunity of achieving good economies of scale since production for every market takes place at just one single location and is fully integrated. Here, the location decision involves finding the best place to manufacture the prod uct, taking into account a wide range of factors such as design capability, engineering compe tence, and availability of low cost productive resources, as well as the need to minimize trans port costs. This last factor is not too easy to determine because the materials, parts, and fin ished goods can come from, and go to, an enormous number of other countries. The dis tribution of finished goods can also present dif ficulties because of the ever changing nature of the market in terms of customer location and product mix.

An alternative and overlapping approach to international location is to consider the configur ation of a company's network at an international level. Four configuration strategies have been identified.

### Home Country Configuration

The simplest strategy for an organization trading around the world is not to locate plants outside its home country and to export its products to foreign markets. The reason for this might be, for example, that the technology employed in the product is so novel that it needs to be manufactured close to its research and develop ment headquarters. Alternatively, the home lo cation of the company might be part of the attraction of a product (e.g., high fashion gar ments from Paris).

### Regional Configuration

An alternative strategy is to divide the com pany's international markets into a small number of regions and make each region as self con tained as possible. So, for example, the Pacific region's market would be served by an operation or operations in that region. Companies might adopt this strategy because their customers demand speedy delivery and prompt after sales service. If products or services were created out side the region, it might be difficult to provide such a level of service without regional ware houses and service centers.

### Global Coordinated Configuration

The opposite of the regional strategy is the global coordinated configuration. Here each plant concentrates on a narrow set of activities and products and then distributes its products to markets around the world. So, for instance, a company might take advantage of low labor costs in one region and the technical support infrastructure in another in order to seek to exploit the particular advantages of each site or region. However, by doing so, it does place a coordination requirement on the headquarters of the company. All product allocations, operations capacities, and movement of products are planned centrally.

### Combined Regional and Global Coordinated Configuration

The regional strategy has the advantage of or ganizational simplicity and clarity, the global coordinated strategy of well exploited regional advantages. Firms often attempt to seek the ad vantages of both by adopting a compromise be tween them. Under such a strategy regions might be reasonably autonomous, but certain products could still be moved between regions to take advantage of particular regional circum stances.

See also *global manufacturing network; industrial networks; location*

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## International Motor Vehicle Program (IMVP)

*Matthias Holweg*

The International Motor Vehicle Program (IMVP) is one of the longest standing research efforts in the automotive industry, and probably best known for its international BENCHMARK ING study which led to the book *The Machine that Changed the World* (Womack, Jones, and Roos, 1990). The program has its roots in re search that started at the Massachusetts Institute of Technology (MIT) in the late 1970s, looking into general trends in the automotive industry and culminating in the first book about IMVP (then still called MIT's International Automo bile Program), *The Future of the Automobile* (Altshuler et al., 1984).

At a time when increasing imports of Japanese automobiles threatened the manufacturing bases in the US and Europe, the research was expanded into a global comparative analysis of vehicle assembly operations. Although the first books on JUST IN TIME and the Toyota pro duction system (TPS) were already available in

English (cf. the works of Yasuhiro Monden, Richard Schonberger, Robert Hall, and William Sandras), claims that Japan was more productive were still dismissed by western manufacturers. A common argument at the time was that Japanese makers were simply more productive (measured in terms of "labor hours per vehicle") because they were building smaller vehicles, which re quired less effort than making larger (American) cars.

In 1985, IMVP started a global assembly plant survey, based on a methodology developed by MIT researcher John Krafcik, which controlled for the difference in vehicle size and thus pro vided an objective comparison of the PROD UCTIVITY and QUALITY levels in western and Japanese assembly plants. The findings showed a performance gap of up to 2 : 1 in productivity and quality between the US and Japan. The "secret" of Japan's superiority in manufacturing was described as LEAN PRODUCTION, a term attributed to Krafcik (who initially considered calling it "fragile production").

Over a time span of a decade, three rounds of the global assembly plant study were conducted: in 1989 (by Krafcik and John Paul MacDuffie, published in Womack et al., 1990); in 1994 (by MacDuffie and Frits Pil); and in 2000 (by Pil). The longitudinal analysis of all three rounds combined can be found in Holweg and Pil (2004).

Apart from the continuing international benchmarking work, IMVP also expanded its research agenda into many aspects of the auto motive supply chain: supplier relationships, product development (for more detail see Cusumano and Nobeoka, 1998), e commerce (*see* E BUSINESS; E INTERMEDIARIES), glob alization, and the implementation of BUILD TO ORDER strategies.

Over its history of more than 20 years, the program has been host to the works of Jeffrey Dyer, Charles Fine, Marshall Fisher, Takahiro Fujimoto, Susan Helper, Richard Lamming, Mari Sako, Koichi Shimokawa, and Akira Takeishi, to name just a few. Current working papers can be found at http://imvp.mit.edu.

See also *history of operations management; new product development process*

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## inventory accuracy

*John Mapes*

Inventory accuracy is a measure of the extent to which inventory records are in agreement with actual stock counts. High levels of inventory accuracy are necessary in order to properly con trol inventory levels and reduce the risk of stock outs. As soon as any difference is discovered, the stock records should be adjusted to reflect the physical stock available and a corresponding adjustment made to accounting records. In order to monitor stock accuracy, each item of stock must be physically counted at regular intervals. Two methods are available for doing this: periodic inventory counting and cycle in ventory counting. Periodic inventory counting involves physically counting every item of stock at the same time, usually once a year. Cycle inventory counting involves physically counting a few items of stock each day or week so that at the end of a specified time interval all items have been counted.

Periodic inventory counting is the auditing of the physical stock on hand for every item of stock over a short period of time at regular intervals. It is usually carried out on an annual or semi annual basis. It requires all operations to be closed down during the period of stock taking and so it can be extremely disruptive. Because of the need to complete the audit as rapidly as possible, non specialist staff are usually brought in to help and this can lead to errors. It also results in a large number of adjustments and write offs occurring at the same time, placing a considerable load on the departments concerned.

Cycle inventory counting is the auditing of a few items at a time on a continuous basis throughout the year. It can be carried out by stores personnel as part of their normal duties and so it tends to be more accurate and less disruptive. It also provides a continuous measure of inventory accuracy. If the level of accuracy is unacceptable, action can be taken to identify the causes of errors and eliminate them. One of the attractions of this method is its flexibility. High usage items can be counted more frequently than low usage items. Items can be counted when stocks are likely to be at their lowest, e.g., when a replenishment order has just been received. Items can be counted when an error might be critical, e.g., when a replenishment order is about to be placed or stock records show a zero or negative stock level.

See also *inventory management; inventory performance measures; inventory related costs; inventory valuation*

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## inventory control systems

*John Mapes*

Inventory control systems are the systems employed in order to insure that inventories are kept at the minimum level consistent with maintaining continuity of supply to meet the needs of external customers and users within the business. The inventory control system must provide answers to the following two questions for each item stocked:

1 When should the stock be replenished?
2 What quantity should be ordered at that time?

In very broad terms there are two categories of inventory control systems. There is the continuous review system (also called the perpetual inventory system) where the inventory level is monitored continuously. As soon as the inventory level falls below a predetermined level, then an order is placed for the reorder quantity. The alternative system is the periodic review system. Here the inventory level is checked at fixed intervals only, say once a month. An order is then placed of sufficient size to bring total inventory up to a specified maximum level.

### The Continuous Review System

In the continuous review system of inventory control a fresh order is placed as soon as the inventory level falls to a level equal to the expected lead time demand plus a safety stock to allow for those occasions when lead time demand is higher than expected. The size of the safety stock depends on the desired stockout risk and the variability in lead time demand. The most common measure of variability in lead time demand is the standard deviation. Various statistical methods are available to determine what multiple of the standard deviation is necessary as safety stock in order to achieve the required stockout risk.

### The Periodic Review System

The main drawback of the reorder point system is that continuous review of inventory levels is implied. This, in turn, means that posting of stock movements has to be kept up to date, and inevitably an unpredictable workload is to be expected, particularly for the purchasing department. This can be avoided using the periodic review system. In its pure form, the inventory level is reviewed at regular intervals and a replenishment order is placed at each review.

The basic periodic review system involves regular reviews of all stock items, although the frequency and time of review will not necessarily be the same for all stock items. In general, items with large annual requirement values will be reviewed frequently and items with low annual requirement values will be reviewed infrequently. At each review an order is placed sufficient to bring total inventory up to a maximum level equal to expected demand during the review period and lead time plus a buffer stock to cover above average demand during this period. This can lead to orders being placed for very small numbers of items, but the system becomes very attractive when a large number of different stock items can be ordered from the same supplier at the same time.

See also *economic order quantity; inventory accuracy; inventory management; inventory performance measures*

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## inventory management

*John Mapes*

All goods and materials that are held by an organization for future use or sale are called inventories or stocks. Inventory management involves planning and controlling these inventories with the objective of meeting the material requirements of the organization at the lowest possible cost.

### Categories of Stock

From an accounting point of view, there are four categories of inventory: raw materials, spares and supplies, work in progress, and finished goods. However, from an operations management (OM) viewpoint it is more important to categorize inventory in terms of why it is there, i.e., the purpose for which the stock is held. Using this approach, the following categories can be identified.

1. *Lot size inventories*. When ordering materials from an outside supplier, there is a fixed cost associated with placing and expediting the order that is independent of the quantity ordered. It is therefore sensible to spread this fixed cost over a number of items by ordering in fairly large quantities at infrequent intervals. The quantities ordered will take some time to be consumed and will in the meantime have to be held as inventory. These inventories are referred to as lot size or cycle inventories.
2. *Fluctuation inventories*. Demand for stock items during the period between placing a replacement order and receiving the goods is subject to unpredictable fluctuations. To give protection against these fluctuations, a safety (or buffer) stock is held.
3. *Anticipation inventories*. When demand shows pronounced seasonal variation, it is often difficult for a manufacturing company to justify providing enough capacity to meet peak demand. Instead, stocks are built up during periods of low demand and held until needed during the seasonal peak. Inventories that are deliberately built up in this way for consumption at a later date are called anticipation inventories.
4. *Decoupling inventories*. In manufacturing processes involving a number of linked stages, a delay at one stage can lead to delays at later stages in the process as these stages run out of work. To reduce the chances of this happening, decoupling inventories (also called buffer stocks) are placed between the stages.

In recent years major changes have taken place in the inventory management task. Initially, the emphasis was on cost minimization. Mathematical techniques were developed to determine the optimum inventory levels necessary to provide an acceptable risk of stock non availability at minimum cost. As computers became more widely available, MATERIAL REQUIREMENTS PLANNING systems were developed capable of rapidly translating product requirements into a detailed schedule of time phased orders for raw materials, components, and subassemblies. The next development was JUST IN TIME management. This approach emphasized the identification and elimination of the inefficiencies that result in high levels of inventory. Such inefficiencies include long setup times, late delivery from suppliers, unreliable machines, and inflexible production processes.

$$\text{Stock turn} = \frac{\text{value of materials used over a period}}{\text{average stock value over the period}}$$

Another measure which is sometimes used is a week's usage:

$$\text{Week's usage} = \frac{\text{average stock value over a period}}{\text{average stock value of materials used per week during the period}}$$

**Figure 1** Inventory turnover

See also *aggregate capacity management; economic order quantity; inventory control systems; inventory related costs; lot sizing in MRP; product layout; purchasing*

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## inventory performance measures

*John Mapes*

Measures of inventory performance consist of two main types. The first is concerned with how well inventory levels are being controlled, and the most common measure is inventory turnover. The second is concerned with how good a service the inventory function is providing to users. The most common measure of this is customer service level. Although all organizations monitor the total value of stocks held, this figure is not very useful when viewed in isolation. It needs to be related to the value of material usage. The most common measure used to do this is inventory turnover. This gives an indication of the number of times the inventory has been consumed or turned over during a specified period, usually a year (figure 1). The two measures are just different ways of presenting the same information. Each can be derived from the other.

Customer service level is a measure of the percentage of customer requirements that have been met during a given period. There is a wide variety of different ways in which customer service level can be measured depending on how customer requirements are defined. If the emphasis is on measuring inventory performance, then a typical measure of customer service level might be as shown in figure 2.

See also *inventory accuracy; inventory control systems; inventory management*

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## inventory-related costs

*John Mapes*

The costs associated with inventory can be divided into four categories.

### Purchase Cost

Purchase prices will usually be affected by the quantity ordered. For large quantities bulk discounts can usually be negotiated. The purchase

$$\text{Customer service level} = \frac{\text{value of orders met immediately from stock during a period}}{\text{total value of orders during the period}}$$

**Figure 2** Customer service level

price is also likely to vary over time, so that timing of the order may affect the price paid. Building up inventories prior to a known price increase may be financially advantageous even after taking into account the resulting increase in stockholding costs. The prices of many commodities show marked fluctuations over time, so that average unit prices can be reduced by building up inventories when prices are low and running down inventories when prices are high.

### Ordering Costs

Whenever an order is placed with an outside supplier there is the cost of selecting a vendor, agreeing a price, processing the paperwork, transporting the goods, and arranging for payment. Most of these costs will be independent of the actual quantity ordered and so total ordering costs can be reduced by ordering less frequently in larger quantities. When an order is raised for a product or component to be manufactured internally, there is the cost of raising the paperwork and setting up the machine.

### Inventory Holding Costs

Inventory holding costs are all of the costs that are incurred as a result of an item being held in stock. They include the cost of the capital tied up, the warehouse space occupied, warehouse staff, insurance, damage, deterioration, and obsolescence. The cost of holding an individual item in stock is quite difficult to measure and so annual stockholding cost for each item is usually expressed as a set percentage of its average stock value.

### Stockout Costs

When an item is required that is out of stock, then the costs incurred will depend on the circumstances. In some cases it may be possible to obtain the items from another site or from an outside supplier sufficiently rapidly to still meet the requirement. The costs incurred will include the costs of locating the items, arranging special delivery, and perhaps paying a premium on the normal price for the items. In other cases a back order may be possible, the customer being willing to wait until the item is available. The costs will include the additional paperwork and labor costs involved in processing the back order and notifying the customer. If the customer is not willing to wait, then a lost sale will result. Not only will there be the lost profit on the sale, but there will also be goodwill costs. Customers may decide to place future orders elsewhere, they may make adverse comments to other customers, and so on.

See also *economic order quantity; inventory accuracy; inventory management; inventory valuation; purchasing*

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## inventory valuation

*John Mapes*

Inventory valuation is the procedure used for determining the value of inventory held by the organization. Inventory usually constitutes a significant proportion of total assets and so the inventory valuation method adopted can affect the company's apparent worth. Also, the value assigned to stock withdrawals helps determine the cost of goods sold, which in turn affects the profit during a period. Inventory valuation is complicated by the fact that stocks of each item are continually being used up and replenished and the unit price is likely to be different for each replenishment. The following methods are the ones most commonly used for valuing inventory.

### First In, First Out (FIFO)

Here it is assumed that the items are used in strict chronological order of receipt. When an item is withdrawn from stock, the unit price used is that of the earliest order from which the item could have come. For most items, particularly those with a limited shelf life, FIFO corresponds with the actual order in which items are issued. Calculation of prices is fairly simple and the value of inventory remaining approximates to its current value as it is based on the prices of those items purchased most recently. However, during periods of inflation, the cost of goods sold will be lower than would be the case if current material costs were used.

Last In, First Out (LIFO)

Here it is assumed that the most recently re ceived items are issued first. When an item is withdrawn from stock, the unit price used is that of the most recent order from which the item could have come. LIFO is unlikely to correspond with the order in which items are actually issued from stores. Its aim is to take a more conservative view of profits during periods of rising prices, reflecting the fact that inventories consumed have to be replenished at current prices. During inflationary periods this leads to lower tax liability and more cash in hand.

Average Cost

This method attempts to achieve a compromise between the extremes of FIFO and LIFO. Once an item enters stock, it is assumed to be identical to all other items of the same type and they are all valued at the same average price. This average price is then used as the valuation for all with drawals from stock until the next order is re ceived and a new average price calculated. The advantage of averaging is that it smoothes out fluctuations in purchase prices. This carries with it the disadvantage that when prices are consist ently rising or falling, the average price lags behind current prices.

Specific Cost

For large, expensive items, each item can be given an identification number and the purchase price recorded. Then, when the item is used, it can be valued at the specific price paid for it. While this is the most realistic method of valu ation, it involves a considerable amount of record keeping. For the majority of items the benefits gained do not justify the recording cost.

See also *economic order quantity; inventory accuracy; inventory management; inventory related costs; purchasing*

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# J

*jidoka*

*Par Ahlstrom*

In the Toyota production system (TPS), a key concept supporting excellence in manufacturing is *jidoka*, often (rather clumsily) translated as "autonomation." *Jidoka* is a technique for detecting and correcting production defects. It incorporates a mechanism to detect abnormalities or defects and a mechanism to stop the line or machine when abnormalities or defects occur. *Jidoka* is not limited to machine operations but can be used in conjunction with manual operations. Human *jidoka* allows operators to stop the process in the event of a problem. This would often involve visual control, which is the means of assessing, at a glance, the status of production processes and the visibility of process standards.

The concept of *jidoka* is aimed at describing humanization of the human/machine interface. The philosophy behind *jidoka* is that people remain free to exercise judgment, while the machine serves their purposes. When the equipment stops automatically, there is no need for a worker to oversee the machines. This helps save costs as it becomes possible to decrease the work force. Furthermore, since all machines stop when they have produced the required amount of parts demanded from customers, there is adaptability to changes in demand. When a defective part is noticed, the line stops immediately and an investigation is started to find causes, correct the fault, and then take corrective action to prevent the fault from occurring again. The manner in which *jidoka* calls attention to defects and stimulates improvement activities increases respect for humanity, according to Toyota. Central to the concept of *jidoka* is the assurance that all parts are produced fault free from the beginning. To insure a swift and even flow of materials, it is absolutely necessary that all parts are fault free. To further help achieve a smooth flow of materials, the use of small machines is favored. The idea here is that several small machines are used in preference to a single, large machine. Small machines are held to be less prone to BOTTLENECKS, lengthy MAINTENANCE, and the buildup of inventories (*see* INVENTORY MANAGEMENT). This helps achieve the necessary prerequisite of small lot production and reduction of lead times, without which just in time production cannot be realized. A further prerequisite for just in time production is the focus of attention on the flow of materials, not on capacity utilization. Capacity utilization will, if pursued mindlessly at all stages of a manufacturing process, eventually lead to a large buildup of inventories (*see* CAPACITY MANAGEMENT; CAPACITY STRATEGY).

See also *human centered CIM; just in time; kanban; lean production*

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## JIT and MRP/ERP

*Alan Harrison*

Although just in time (JIT) and material requirements planning/enterprise resource planning (MRP/ERP) approaches to planning and control have often been caricatured as divergent philosophies (i.e., western "complex and technological" versus eastern "simple and human centered"), the two approaches are more pragmatically seen as being complementary. At the very least, JIT can be seen as having much to contribute to conventional MRP/ERP systems solutions. Perhaps most significantly, while MRP excels at planning and coordinating materials, it is relatively weak in its control of the timing of material movements and the complexity of MRP may become a liability at shop floor level, where control systems are comparatively cumbersome and unresponsive. Yet the comparative simplicity resulting from such JIT techniques as LEVELED SCHEDULING and KANBAN can greatly help to simplify shop floor control of parts, especially those which are made at regular intervals, sometimes termed "runners" and "repeaters" (*see* RUNNERS, REPEATERS, AND STRANGERS). Further, JIT concepts can be used to attack many of the wasteful assumptions that are often built into MRP, such as fixed reorder rules and scrap allowances. There are a number of ways in which the overall control of complex operations through MRP and the improvement oriented simplicity of JIT can be combined at a technical level. Two general approaches to this are particularly influential:

1 The use of different planning and control systems for different products. Using the runners, repeaters, and strangers terminology, pull scheduling using *kanbans* can be used for "runners" and "repeaters," while MRP is used for "strangers." For "strangers," works orders are issued to explain what must be done at each stage and the work itself is monitored to push materials through manufacturing stages. One advantage of this approach is that by increasing responsiveness and reducing inventories of runners and repeaters, it encourages operations to increase their number by design simplification.
2 The use of MRP for overall control and JIT for internal control. So, for example, MRP is used for the planning of supplier materials to insure that sufficient parts are available to enable them to be called off "just in time." The MASTER PRODUCTION SCHEDULE is broken down by means of MRP for supplier schedules (forecast future demand). Actual material requirements for supplies are signaled by means of *kanbans* to facilitate JIT delivery. Within the factory, all material movements are governed by *kanban* loops between operations.

The relative complexity of both product structures (gauged by the number of levels in the BILL OF MATERIALS) and process routing (gauged by the number of processes through which parts must travel) has an important influence on which planning and control system is used. Where there are simple structures and routings, internal material control merits simple systems such as JIT based systems. As complexity increases, so the power of the computer is needed to break down forecast demand into supplier schedules through MRP, but much internal control can still be carried out by means of pull scheduling. As structures and routings become more complex, so the opportunities for pull scheduling reduce, and MRP is needed to coordinate material movements. Network planning and control systems are needed for the most complex structures and routings.

See also *enterprise resources planning; just in time; lean production; manufacturing resources planning; material requirements planning; scheduling*

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**JIT tools and techniques**

*Alan Harrison*

A more or less coherent set of operational tools and techniques is associated with the just in time (JIT) philosophies of customer pull and waste minimization. Many of these techniques are not new, nor indeed exclusive to JIT applications, but lean production proponents hold that it is their effect in particular JIT related combinations that is significant. It is possible to further categorize these techniques according to their purpose: *simplifying* or *integrating*.

Simplifying techniques include:

- *Design for manufacture*: The JIT emphasis on simplicity in manufacture is complemented by design approaches with similar aims such as VALUE ENGINEERING and SIMULTANEOUS DEVELOPMENT.
- *Simple layout and flow*: This approach involves using LAYOUT principles to achieve a drive toward shorter routings by moving machines and processes closer together whenever the opportunity arises. This reduces wasted effort in the transport of materials.
- *Focus*: The concept of focus is that the operations task has been limited to a simple, consistent, and achievable set of goals. Again, this approach enhances the simplicity of operational practice. Product focus is a major feature of many of the best JIT companies.
- *Small machines*: The principle here is that several small machines are used in preference to a single, large one. Small machines can be less prone to BOTTLENECKS, lengthy MAINTENANCE, and the buildup of inventories (*see* INVENTORY MANAGEMENT).
- *Total productive maintenance (TPM)*: The principle here is to assure maximum equipment availability at minimum cost, but also to contribute to the JIT principle of dependability in the operation.
- *Setup reduction*: Cutting down the time it takes to change equipment over from producing one batch to the next is key to improving FLEXIBILITY without losing capacity. In turn, this helps to reduce inventories and throughput times (*see* CAPACITY MANAGEMENT).
- *Team preparation*: Assigning people to product work areas within a developing total quality climate is the start of team preparation. It continues with developing operators who are multiskilled and multifunctional, so that they can carry out all processes, conduct routine maintenance, are responsible for QUALITY, and are involved in improvement activities (*see* EMPOWERMENT; GROUP WORKING).

Integrating techniques (which are often dependent upon previous experience with simplifying techniques) include:

- *Flow scheduling*: The principle here is to keep materials moving. Keeping machines and people busy is less important. Parts and subassemblies are kept moving throughout the operations system to the "direction" of the factory assembly schedule. The analogy to water is often used in JIT literature, in this case clear the river bed of rocks and obstructions and straighten its path to shorten and even the flow of the river and its tributaries (*see* LEVELED SCHEDULING).
- *Inventory reduction*: This is often one of the most visible benefits of JIT. It is accomplished by reducing batch sizes and buffer stocks following improvements in setup times, productive maintenance, and flow scheduling.
- *Visibility*: A JIT influenced factory is often recognizable from the charts and check sheets that are on show to record the status of operations processes and improvement projects, and from the light and/or sound indicators that monitor running conditions. Such relatively simple devices are much favored in JIT philosophy both for their simplicity (hence robustness) and their transparency of operation (contributing to a culture of shared information and objectives).
- *Enforced improvement*: This approach is intended to further identify and reduce waste. Enforced improvement is concerned with deliberately creating pressure for change. As each improvement project is

implemented, the question is asked, "what further improvement does this enable us to do now?" For example, setup reduction may help to reduce batch sizes and buffer stocks. In turn, this helps to improve layout because processes can be placed closer together, which in turn improves visibility, and so on.

See also *design chain; design for manufacture; focus; kanban; lean production; just in time; setup reduction; total productive maintenance*

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## job design

*David Bennett*

Job design is a general term given to the aspect of operations system design which relates to the way in which jobs are structured and workers motivated. The activity of job design has been influenced by several concepts. In chronological sequence, these are DIVISION OF LABOR, SCIENTIFIC MANAGEMENT, ERGONOMICS, and, more recently, approaches to job design based on theories of motivation such as JOB ENRICHMENT, JOB ENLARGEMENT, JOB ROTATION, and EMPOWERMENT.

The term job design is sometimes taken to refer only to this latter influence, which originates from the Hawthorne studies that were carried out in the Hawthorne works of the Western Electric Company in the US. Intended originally to be a straightforward investigation into the effect of different lighting levels on output, the studies developed into a series of experiments which increasingly demonstrated that human behavior was an important factor affecting operating system performance and which had, up to that time, been grossly under estimated by managers. This recognition that the design of jobs was important was later refined by considering the issue of workers who were organized into groups. This work was carried out in the 1950s by the Tavistock Institute of Human Relations in London and used the coalmining industry as its research base. It demonstrated that informal structures and relationships were just as significant as the formal ones. The Tavistock work led to a whole new area of job design, that of "sociotechnical systems" design. This new approach was based on the fact that it is frequently impossible to separate the design of jobs from that of the physical, or technical, system.

In general terms, job design can be categorized into two broad approaches: those which are based on "horizontal job loading" and those based on "vertical job loading."

Horizontal job loading, more commonly known as job enlargement, means that jobs are extended horizontally. That is to say, the length of workers' tasks is increased or further similar tasks are added. Alternatively, the variety of products with which the worker is involved can be increased. A variation on this idea is job rotation, where workers move from one job to another as a way of extending the scope of tasks.

Vertical job loading, more commonly known as job enrichment, means that jobs are extended vertically. More satisfying jobs are created by adding work of a different level. For example, tasks of greater complexity can be carried out or further responsibilities can be assigned such as production planning, material ordering, quality control, or maintenance.

The "output" of the job design activity can be seen as a set of interrelated decisions, including the following:

- the tasks that are to be allocated to each person in the operation;
- the sequence of tasks to be established as the approved manner to do the job;
- the location of the job within the operation;
- who else should be involved in the job;
- the interface with the facilities and equipment used in the job;
- the environmental conditions that should be established in the workplace;
- the degree of autonomy to include in the job;

- the skills to develop in staff.

Job design has received increased attention, par ticularly as a result of the problems that have arisen with some of the more conventional pro duction systems. These problems are probably most acute in line operations where cycle times are short and tasks are highly repetitive, which leads to monotonous jobs with little to motivate the worker.

Increasingly, this situation has led to radical measures being taken to redesign jobs with en tirely new types of production system being designed based on CELL LAYOUT or using GROUP WORKING. In these systems, work cycles are extended and groups can, within reason, organize their own work, which brings the benefits of job enlargement, job rotation, and job enrichment mentioned above.

See also *method study; teleworking; work organ ization*

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## job enlargement

*David Bennett*

Job enlargement is an approach to JOB DESIGN which provides a way of increasing job satisfac tion and motivation. It is also known as horizon tal job loading, which means that jobs are extended horizontally. That is, the length of workers' tasks is increased or further similar tasks are added. Alternatively, the variety of products with which the worker is involved can be increased. A variation on this idea is JOB ROTATION, where workers move from one job to another as a way of extending the scope of tasks.

The essential point about job enlargement is that a greater amount of work is carried out as a way of increasing worker involvement, but the level of work remains unchanged. This can lead to greater job satisfaction and, as a result, higher performance and better quality of output, but the degree to which it provides greater self ac tualization is limited. For this reason, an alter native approach is often used known as JOB ENRICHMENT, or vertical job loading, in which tasks of greater complexity are carried out or further job responsibilities are assigned.

See also *division of labor; empowerment; group working; method study; teleworking; work organ ization*

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## job enrichment

*David Bennett*

Job enrichment is an approach to JOB DESIGN which provides greater self actualization than JOB ENLARGEMENT or JOB ROTATION. It is also known as vertical job loading, which means that jobs are extended vertically rather than horizontally. That is, more satisfying jobs are created by adding work of a different level in stead of merely increasing the amount of work carried out.

To provide job enrichment, tasks of greater complexity can be carried out or further respon sibilities can be assigned such as production planning, material ordering, quality control, or maintenance. In this way, workers are given greater responsibility and, as a consequence, their motivation improves. This can result in a more flexible and adaptable workforce, which is particularly appropriate within the context of modern operations systems.

Job enrichment programs are often coupled with other production system redesign measures to maximize the benefits they can offer. These include creating cellular layouts (*see* CELL LAYOUT) and GROUP WORKING, which pro vide the structural mechanisms for vertically extending jobs.

See also *division of labor; empowerment; method study; teleworking; work organization*

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## job rotation

*David Bennett*

Job rotation is a variation on JOB ENLARGE MENT, which itself is an approach to JOB DESIGN for increasing job satisfaction and mo tivation. Job rotation means that workers move from one job to another as a way of extending the scope of tasks, so it is a form of horizontal job loading. This means that jobs are extended hori zontally but the level of work remains un changed.

The essential point about job rotation is that a greater variety of work is carried out as a way of reducing the monotony associated with perform ing repetitive tasks continuously. It is most com monly used in line operations where other job design approaches are more difficult to imple ment owing to the restrictions of the physical system. It can lead to greater job satisfaction and, as a result, higher performance and better qual ity of output, but the degree to which it provides greater self actualization is limited. To over come this drawback, it is sometimes linked with teamworking, where members of the team can organize their own work assignments and achieve a greater sense of responsibility.

See also *division of labor; empowerment; group working; job enrichment; method study; telework ing; work organization*

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## Juran

*Rhian Silvestro*

Joseph Juran, like Deming, established his repu tation as a consultant in quality management during the 1950s when he was invited to give a series of lectures on the subject at the Japanese Union of Scientists and Engineers (JUSE).

Juran's definition of quality as "fitness for purpose or use" from the customer's perspective focused management attention on the needs of both internal and external customers. Stressing the importance of commitment from senior management in improving quality, he ascribed over 80 percent of quality problems to poor management rather than poor workmanship.

Juran also contributed the concept of the quality trilogy – quality planning, control, and improvement – and advocates the use of statis tical methods of quality control, while warning against acceptance of "chronic waste." He recommends the following breakthrough procedure:

1 Convince others that a breakthrough is needed.
2 Identify the vital few projects.
3 Organize for a breakthrough in knowledge.
4 Conduct an analysis to discover the cause(s) of the problem.
5 Determine the effect of the proposed changes on the people involved, and find ways to overcome resistance to these changes.

6 Take action to institute the changes, includ ing training of all personnel involved.
7 Institute the appropriate controls that will hold the new, improved quality level but not restrict continued improvement.

He also stresses the importance of preventive maintenance, but differs from other exponents of TOTAL QUALITY MANAGEMENT in that his model of optimum quality costs implies that as defect levels decrease, failure costs are reduced while the costs of appraisal and prevention increase, thus accepting an implicit trade off between quality and cost.

See also *Crosby; Deming; Feigenbaum; quality; quality management systems; trade offs*

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## just-in-time

*Par Ahlstrom*

The term "just in time" (JIT) production is used to characterize an approach commonly as sociated with developments in Japanese manu facturing during the 1950s and 1960s. Originally positioned as a counter intuitive alternative to traditional western manufacturing models, today it is arguably *the* paradigm for operations man agement (Krafcik, 1988). Yet despite this popu larity, or indeed perhaps because of it, defining JIT is not straightforward. Its exact origins are unclear, although two names have become syn onymous with its development: Shigeo Shingo and Taiichi Ohno. According to the industrial engineer Shigeo Shingo, many of the basic ideas of JIT were developed in electrical, shipbuild ing, and automotive industries. However, the organization most commonly associated with the development of JIT is the Toyota Motor Corporation, under the leadership of Taiichi Ohno. At Toyota, just in time production is defined as "the production of the necessary products in necessary quantities at the necessary time." This means production of the amount of goods that can be sold, when they can be sold. The idea at Toyota is that only customers are free to place demand when they want. It is through just in time production that the com pany can assure the rapid and coordinated move ment of parts throughout the production system to meet that demand. The primary objective is to make the time between customer order and the collection of cash as short as possible.

In addition to the idea of customer pull, the other core philosophy of JIT is the relentless pursuit of waste – every activity that does not add value to the product. Wasteful activities include inspection, producing defective goods, transport, producing more than is needed, and storing products. Waste often shows up as vari ous forms of inventory. Holding parts in stock does not add value to them and inventory should therefore be eliminated. Inventory in the form of work in progress is especially wasteful. Apart from representing committed funds, work in progress also hides problems and keeps them from getting solved. The effects of reducing work in progress, therefore, go beyond that of reducing capital employed. However, since in ventory exists for a reason, it is not advisable to eliminate inventory mindlessly. The causes behind the existence of inventory must be re moved first.

When removing the causes behind the exist ence of inventory, an often used analogy is that of the "ship and the rocks." In this analogy, rocks in the water represent the problems in the production process. These problems have traditionally been covered by water, here repre sented by inventory. It is only by deliberately lowering the level of water that operations man agers can start to understand and prioritize the problems (rocks) that have been hidden under the inventory (water). Having prioritized and solved the problems through enforced problem solving, the rocks are removed and further im provement of the production system is done by lowering the water level again, by removing in ventory. At Toyota, a practical way of achieving this effect is by removing *kanban* cards from the process or by speeding up the line. The aim is to create problems and then solve them as part of an endless pursuit of perfection. A main reason for the existence of work in progress inventory is due to large batch sizes compensating for long setup times. The setup time decides economic ally viable batch sizes, since setup times deter mine the setup cost. By reducing setup cost, cost per unit can be kept constant despite decreasing batch sizes. Reduced batch sizes also improve throughput times. A reduction of setup times is therefore essential (*see* SETUP REDUCTION). Work to reduce setup times was carried out at Toyota in the 1950s and 1960s, resulting in a method commonly referred to as "SMED," single method exchange of die (Shingo, 1985). Through the SMED method, setup times in large punch presses could be reduced from sev eral hours to less than ten minutes. Setup time reduction involves separating tasks that can be performed while the machine is still up and running (external setup) from tasks that require the machine standing still (internal setup).

## History of JIT

The development of just in time production took place when Japanese industry had to be rebuilt after World War II. An important reason for the development of JIT was the nature of the markets in postwar Japan. The markets were not large enough to cope with large volume mass production. Fluctuations in monthly sales fur ther exacerbated the problems of using standard mass production techniques. Some observers have also attributed the growth of just in time production to the scarcity of natural resources in Japan, which led to a focus on eliminating waste – everything that did not add value to the final product. Just in time production did not de velop overnight. While development started in the 1950s, significant ideas were still being re fined during the 1970s. In fact, in line with a fundamental tenet of JIT, CONTINUOUS IM PROVEMENT, one could say that the develop ment of JIT is still ongoing. More significantly, it took a long time before the academic literature in the West started featuring articles on JIT (the first academic article appeared in 1977, written by four Toyota employees). After this, there was a veritable explosion of material written on the topic. Early and important contributions were made by Richard Schonberger in 1982, with the book *Japanese Manufacturing Techniques*, and by Yasuhiro Monden in 1983, with the book *Toyota Production System*.

## Achieving JIT

To achieve just in time production in the broader sense, several techniques need to be implemented. This is an important and often overlooked point. Just in time production cannot be achieved by implementing isolated techniques, such as *kanban* or quality circles. As western companies started traveling to Japan in the mid 1970s to learn from companies such as Toyota, they often came back with isol ated techniques, which were then implemented. The results were often far from satisfactory. Furthermore, implementing these techniques is not easy and will often take a long time. In fact, it took Toyota decades to develop its production system. Companies cannot expect overnight suc cess when implementing JIT. Taiichi Ohno argued that JIT production at Toyota was reliant on three central techniques:

1 Production smoothing (*heijunka*), which is the leveling and smoothing of the flow of materials (*see* LEVELED SCHEDULING). By applying *heijunka*, a production line is no longer committed to producing a single type of product in large lot sizes. Instead, the production line produces many varieties to respond to customer demand. Through *heijunka*, production is kept up to date and in line with customer demand, resulting in less inventory.
2 The use of the *kanban* system to inform manufacturing processes of the necessary timing and quantity of production. Through *kanban*, a subsequent process instructs a pre ceding process to send the exact number of parts, exactly when the parts are needed.
3 LAYOUT principles that aim to achieve a smooth flow of materials (*nagare*). *Nagare* involves achieving shorter travel distances for material, by moving machines and pro cesses closer together whenever the oppor tunity arises. Through *nagare*, the amount of wasted effort in the transport of materials can be reduced. The preferred layout is U shaped. With this shape, the range of work performed by workers can be widened or narrowed very easily. This layout assumes

the existence of multifunctional workers, who can perform several jobs in the manu facturing process.

As part of the pursuit of waste, simplicity is a recurring theme in just in time production. Complexity, clutter, and excessive paperwork are seen as alien to an excellent company. Several tools and techniques are deployed to transform previously complex, cluttered, and variable tasks into simple and clear tasks with increasingly low levels of variability and high levels of accuracy. These tools and techniques themselves tend to be relatively simple to understand and use. The idea of doing the simple things right within manufacturing is further linked to the key notion of doing things gradually better, squeezing out waste at every step. In this process, zero is often used as a goal and an absolute standard: zero defects, zero inventories, zero downtime, etc. These goals act as a focus for improvement ac tivities. While companies may be far from achieving perfection, the argument is that they can get closer to these ideals over time if all company members follow the shared vision. Such visioning forms a key part of the JIT phil osophy, provides goals to aim for and to measure progress against, coordinates improvement efforts, and communicates purpose. Continuous improvement is concerned with making never ending progress toward perfection. In this work, the involvement of the workforce is crucial. At the heart of the continuous improvement pro cess are natural work teams who use simple problem solving tools to identify and solve prob lems that affect their work. The teams may be supplemented by small group improvement ac tivities, which are cross functional teams aimed at specific problems that demand a broader base to solve.

Finally, the core ideas of JIT need to move beyond the confines of the manufacturing func tion. First, the principles of *heijunka*, *kanban*, and *nagare* can be applied throughout the supply chain. Suppliers can also be involved in joint development programs for new products, and generally more closely integrated with the com pany through partnership arrangements. Second, distribution should be included. Closer coordination with actual customer demand can be achieved through such approaches as tightly coupled LOGISTICS with customer processes and just in time delivery. Third, design should be included, with a focus on designing products that are easy to assemble and manufacture at low cost. Through cross functional teams, the time from concept to finished product can be re duced.

## Criticisms of JIT

JIT production has not gone without criticism. At the core of these criticisms are possible nega tive effects on the workforce. The term "Japani zation" has been used pejoratively to focus on the social aspects of work organization that JIT is held to cause. Particular emphasis has been laid on the stressful environment allegedly caused by JIT. One argument is that JIT works in a Japan ese context because of its appeal to the Japanese characteristics of discipline and teamworking. There is some disagreement in academic litera ture as to whether JIT is essentially people building or whether it intensifies work (Oliver and Wilkinson, 1992). Further, employment practices in major Japanese companies empha size other characteristics that would be problem atic to copy in the West, such as lifetime employment and single company trades unions. However, these characteristics are not central to the functioning of JIT and need therefore not be implemented in the West.

See also *International Motor Vehicle Program; jidoka; JIT and MRP/ERP; JIT tools and techniques; kanban; lean production; Seiri, Seiton, Seiso, Seiketsu, and Shitsuke (5S); work organization*

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# K

***kanban***

*Par Ahlstrom*

*Kanban* is Japanese for "card" or "signal" and is a tool to help achieve just in time production. *Kanban* is essentially an information system that informs processes of the necessary timing and quantity of production. Originally, the *kanban* was a card, put in a vinyl envelope. Other vari ants of *kanban* include tokens, messages, and computer based *kanbans*. Through *kanban*, a customer (or subsequent process) instructs a supplier (or preceding process) to send more parts, when the parts are needed. This is known as "pull scheduling" (*see* PUSH AND PULL PLANNING AND CONTROL). *Kanban* can be used both inside a company's manufac turing process and between a company and its suppliers. There are two main types of *kanban* used inside a company:

1. *Withdrawal kanban* is used to signal to a subsequent process that parts can be with drawn from the preceding process. This type of *kanban* would normally have details of the part's name and number, the place from where it should be taken, and the destination to which it is being delivered. When *kanban* is used between a company and its suppliers, a supplier *kanban* is used. It is a form of withdrawal *kanban*.
2. *Production kanban* is used to signal to a pre ceding process that it can start producing a part. This type of *kanban* would normally have details of the part's name and number, a description of the process itself, the mater ials required for the production of the part, and the destination to which the part needs to be sent when it is produced.

There are two different methods of using *kanban*, known as the single card system and the dual card system. The single card system uses only withdrawal *kanbans* and has the benefit of being easier to operate. The dual card system uses both withdrawal and production *kanbans* and has the benefit of giving tighter control, but it is more complex to operate. To realize just in time production through *kanban*, a number of simple rules need to be followed:

- The subsequent process should withdraw the necessary parts from the preceding pro cess in the necessary quantities at the neces sary point in time.
- Any withdrawal without a *kanban* or which is greater than the number of *kanbans* is pro hibited.
- The preceding process should produce its parts in the quantities withdrawn by the subsequent process, in the sequence the parts were withdrawn.
- Defective parts should never be sent to the subsequent process.
- The number of *kanbans* should be progres sively reduced over time, to minimize the amount of inventory.
- The *kanban* system should be used only to adapt to small fluctuations in demand, since it has no adaptability for sudden and large variations in demand.

The rules help create order, since they propose a set number of containers, each with a set number of parts and its allocated position. However, using *kanban* requires a repetitive manufactur ing process. *Kanban* is also inappropriate for seldom used parts. A further potential limita tion is disruptions through breakdowns or absenteeism, which may result in excessive stock or make the manufacturing system inoperable.

See also *International Motor Vehicle Program; jidoka; just in time; JIT and MRP/ERP; JIT tools and techniques; lean production; Seiri, Seiton, Seiso, Seiketsu, and Shitsuke*

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## kit bill

*Pamela Danese*

The kit bill is a planning bill useful to define the SUPER BILLof a product family (*see* PRODUCT FAMILIES). The concept behind the generation of the kit bill is the identification of the product components common to all product configur ations and of the components specific to each end product configuration (Orlicky, Plossl, and Wight, 1972). As an example, suppose that a manufacturer of toys produces five end product configurations. It will be necessary to create:

1 a kit bill including the components common to all product configurations (i.e., the rect angle);
2 five kit bills including the components spe cific to each end product configuration.

The super bill of the five products will be a single level BILL OF MATERIALS in which the parent will be the pseudo product "toy," and the children the kit bills. The kit bills are mainly used when the products are not characterized by numerous product options. In fact, in this case, modular bills are more adequate (*see* MODULAR BILL).

See also *JIT and MRP/ERP; manufacturing resources planning; material requirements plan ning*

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# L

**last planner**

*Harvey Maylor*

The last planner method involves the production of "look ahead" schedules for 4–6 weeks in advance. These contain the details of activities and provide an opportunity to explore the detailed dependencies between activities that are frequently not identified at higher levels of planning. This is of benefit in itself. However, the main tool is a micro management consideration of weekly schedules. These are prepared from the look ahead schedules and contain all the work activities, broken into half day units or less. This feature is important – that the work unit size is small (around half a day) and consistent between the different activities. These are listed in a table, as demonstrated by the example in table 1 (p. 146). The table shows the preparation of part of a report and presentation by a team with the activities broken down in this way.

The following week the team is able to review its progress simply by taking the same table and adding two extra columns – one for whether the activity was complete or not (just a simple yes or no) and, where an activity had not been completed, why this was the case. Table 2 shows the result that the group achieved for this week.

Table 2 (p. 147) shows the basic analysis that can be performed weekly, the main measure used being that of planned percent complete (PPC). This is calculated as:

PPC = activities completed/intended completed activities

In this case 12 of the 18 activities were completed this week, giving a PPC measure of 67 percent.

The PPC measure works well where there are a number of activities going on at any one time. Weekly review meetings provide the forum for discussing progress, but most important is that this tool provides for ongoing problem solving. Where a group is working together week on week, it provides a means by which review can be carried out every week, and the project process improved as the project progresses. In the above example, the group could meet and discuss the causes of the problems that were faced that week – in this case by the non completion of the project analysis. Why was this? Was it not planned well? Were the time estimates too short? Was the information not made available by someone from within or outside the group? Whatever the reason, the weekly meeting provides an opportunity to make sure that problems are solved at this level, and not left until the post project review to be resolved. Week by week, we should expect the PPC measure to improve. This is a highly visible and easily understood measure and very powerful in communicating with teams.

See also *project control; project management*

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**layout**

*Nigel Slack*

The term layout is used to mean the physical location of an operation's facilities (machines, equipment, and staff) within the operation. It

**Table 1**

| *Activity* | *When* | *Who* | *Notes* |
|---|---|---|---|
| Write outline of chapter 4 | Mon a.m. | All | |
| Write section 4.1 | Mon p.m. | HT and MR | |
| Complete graphics for chapter 3 | Mon p.m. | WF | |
| Complete telephone interviews | Mon p.m. | KR | |
| Write section 4.2 | Tues a.m. | HT and WF | Relies on 4.1 being complete |
| Outline presentation | Tues a.m. | MR | |
| Write section 4.3 | Tues p.m. | HT and WF | Relies on 4.2 being complete |
| Transcribe telephone interview data | Tues p.m. | KR and MR | Relies on interviews being complete |
| Analyze interview data | Wed a.m. | KR and WF | Relies on transcription being complete |
| Write section 4.4 | Wed a.m. | HT and MR | Relies on section 4.3 being complete |
| Write conclusion to chapter 4 | Wed p.m. | HT and MR | Needs all 4 sections complete |
| Outline chapter 5 – data analysis | Thurs a.m. | All | Relies on chapter 4 and the data analysis being complete |
| Write up data analysis | Thurs p.m. | KR and MR | |
| Extract key findings into presentation | Thurs p.m. | HT and WF | |
| Prepare graphics for chapter 5 and presentation | Fri a.m. | WF | |
| Compile report and check flow | Fri a.m. | HT, KR, and MR | Needs all sections complete, graphics to be inserted for chapter 5 later |
| Integrate chapter 5 graphics and print report | Fri p.m. | All | |
| Practice presentation | Fri p.m. | All | |

determines the way in which the transformed resources of the operation (the materials, infor mation, and customers) flow through the oper ation. This, in turn, can affect the costs and general effectiveness of the operation. The term location is more usually applied to the positioning of facilities geographically (*see* INTERNATIONAL LOCATION; LOCATION).

Layout is often a lengthy and difficult task because of the physical size of the transforming resources being moved, although, even when size is not an issue, the re layout of an existing operation can disrupt its smooth running, leading to customer dissatisfaction or lost pro duction. Furthermore, if the layout is poorly designed, it can lead to over long or confused flow patterns and inventories of materials or customer queues building up in the operation. It is the combination of these two points that gives the layout activity its character. Changing a layout can be difficult and expensive to execute, so operations managers are reluctant to do it frequently, yet the consequences of any mis judgments in an operation's layout will have a considerable and usually long term effect on the operation.

There are many different ways of arranging physical facilities. However, most practical layouts are derived from only three basic layout types: FIXED POSITION LAYOUT, PROCESS LAYOUT (sometimes called functional layout), and PRODUCT LAYOUT. A fourth type, CELL LAYOUT, is usually regarded as a hybrid of product and process layout.

**Table 2**

| *Activity* | *Complete* | *Reason why incomplete* |
|---|---|---|
| Write outline of chapter 4 | y | |
| Write section 4.1 | y | |
| Complete graphics for chapter 3 | y | |
| Complete telephone interviews | y | |
| Write section 4.2 | y | |
| Outline presentation | y | |
| Write section 4.3 | y | |
| Transcribe telephone interview data | y | |
| Analyze interview data | y | |
| Write section 4.4 | y | |
| Write conclusion to chapter 4 | y | |
| Outline chapter 5 – data analysis | y | |
| Write up data analysis | n | Analysis not completed in time |
| Extract key findings into presentation | n | Analysis not completed in time |
| Prepare graphics for chapter 5 and presentation | n | Analysis not completed in time |
| Compile report and check flow | n | Awaiting chapter 5 |
| Integrate chapter 5 graphics and print report | n | Awaiting chapter 5 |
| Practice presentation | n | Conclusions not yet ready |
| **Planned percent complete (PPC)** | 67 percent | |

See also *bottlenecks; business process redesign; div ision of labor; group working; production flow an alysis; work organization*

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## lean production

*Michael Lewis*

The original INTERNATIONAL MOTOR VEH ICLE PROGRAM (IMVP) report into the performance of the global motor industry "revealed" the existence of a 2 : 1 difference in PRODUCTIVITY between car assembly plants in Japan and those in the West. The performance differential was ascribed to "lean production" practices that improved productivity through reduced lead times, material and staff costs, in creased quality, and so on. These findings led to a great deal of industry "soul searching" and, perhaps inevitably, further BENCHMARKING studies which appeared to confirm the initial IMVP results. Given such a backdrop, it is un surprising that lean production practices aroused such intense interest. Enhanced prod uctivity has universal appeal, regardless of whether it is Toyota seeking to survive the oil price shock of 1972–3 or any western manufac turer faced with increasingly intensive global competition. Indeed, lean production's origin ators (and transcribers) were able, by formulat ing the "operating problem" as an unceasing battle against waste (or *muda* in Japanese), to make it seem almost axiomatic that lean implied better. Since the original IMVP report, high profile journal articles (Womack and Jones, 1994), another book (Womack and Jones, 1996), and annual "Global Lean Summits" have con tinued the portrayal of lean production as a more or less universal set of management prin ciples for the production of both goods and services: "We've become convinced that the principles of lean production can be applied equally in every industry across the globe and that the conversion to lean production will have a profound effect on human society – it will truly change the world" (Womack, Jones, and Roos, 1990: 7).

## A Critical Appraisal of Lean Production

Concerns with the lean production model, as it was initially derived, can be summarized under three main categories.

1 Much of the interest in lean production prin ciples was based upon the IMVP claim that Japanese manufacturers were twice as effect ive as their western competitors. The meas urement process (especially relating to the unit of analysis employed) has been criticized (Williams et al., 1994), and others (Pilking ton, 1998) have employed similar data to present an equally challenging but more confused picture (see table 1).
2 In Europe, there has been a great deal of debate about how lean production principles will impact upon established production models, in particular those in Germany (Culpepper, 1999) and Sweden. From a crit ical perspective, its effects upon the work force (it often requires deunionization or single union agreements) have been fiercely attacked (Williams et al., 1994) and, more managerially, the demands placed upon workers by lean systems have been high lighted as a problem with respect to ongoing staff recruitment (Cusumano, 1994).
3 Establishing the causal linkages between inputs and outcomes is notoriously difficult in any complex system. Even if one accepts that Japanese vehicle assemblers were (during the late 1980s and early 1990s) much more productive than their western counterparts, any description of how these organizations achieved these superior out comes must be sifted through any number of interpretive filters. For example, the pre dominance of Japanese exemplars raises le gitimate concerns about cultural superficiality. In a similar vein, although benchmarking studies have benefited from close attention to actual practice, many have largely ignored wider economic and market conditions (Katayama and Bennett, 1996). The recent economic difficulties faced by Nissan (forced to merge with Renault), Honda, and Mazda (bought by Ford) suggest that the lean production model may have reflected particular market conditions at a specific point in time.

The final point suggests that it is necessary to distinguish between lean as an outcome and the more ambiguous and uncertain process whereby an operation becomes lean.

## Lean Production as an Outcome

With respect to the competitive impact of lean production at the level of the single firm, regard less of broader concerns over data comparability, it is self evident that achieving similar (or higher) levels of productive activity with similar (or less) resource input is a positive outcome (notwithstanding real concerns over employ ment conditions etc.). Interestingly, investiga

**Table 1** Dollar value add/motor vehicle employee (cf. Japan), 1986–90

| | *1986* | *1987* | *1988* | *1989* | *1990* |
|---|---|---|---|---|---|
| Japan | 67,075 | 84,538 | 103,548 | 105,433 | 107,874 |
| Sweden (/Japan) | 42,776 (0.64) | 52,413 (0.62) | 63,433 (0.61) | 62,723 (0.60) | 63,229 (0.59) |
| UK | 32,263 (0.48) | 39,984 (0.47) | 46,720 (0.45) | 50,547 (0.48) | 53,340 (0.50) |
| US | 77,787 (1.16) | 80,403 (0.95) | 89,034 (0.86) | 94,912 (0.90) | 89,219 (0.83) |

*Source*: Pilkington (1998).

tions into the relationship between profitability and lean production adoption (Oliver and Hunter, 1998) found no statistical significance between high and low users except that high level users exhibited much higher volatility in profits. There is also evidence suggesting that a more strongly contingent perspective on lean production outcomes is necessary. Some research (Katayama and Bennett, 1996) has claimed that lean production is incapable of responding to large oscillations in aggregate demand volumes, arguing that the Japanese economy at the time of the IMVP study was exhibiting very specific characteristics, creating conditions of high and stable domestic demand.

### Lean Production as a Process

The lean production model relates manufacturing performance advantage to adherence to three key principles (Womack et al., 1990; Womack and Jones, 1996):

1. improving flow of material and information across business functions;
2. an emphasis on customer pull rather than organization push (enabled on the shop floor with *kanban*); and
3. a commitment to CONTINUOUS IMPROVEMENT enabled by people development.

As evidence of the paradigmatic nature of lean production, it is interesting to note how these originally counter intuitive principles have become mainstream managerial concerns.

Yet beyond these general rules, the definition of lean production is actually rather vague and confused (Bartezzaghi, 1999). Attempts to empirically assess progress toward lean production have been forced to develop metrics linking together a wide variety of tools and techniques – many based on opposing principles. For example, Karlsson and Ahlstrom (1996) describe 18 different elements (each with its own subelements) of lean production, and the Andersen Consulting Lean Enterprise Research required firms to fill in a questionnaire that typically took five and a half days of managerial time to complete. If no improvement technique is excluded, then defining what actually constitutes the lean production process becomes extremely difficult.

The sheer breadth of these "real" descriptions might suggest that lean production is not easily imitated and, interestingly, evidence for this assertion can be found in the original IMVP work. This study was strongly influenced by Toyota and the work of Taiichi Ohno in particular. When this celebrated engineer wrote his book (Ohno, 1988), after retiring from the firm in 1978, he was able to portray Toyota's manufacturing plants as embodying a coherent production approach. This was a powerful advertisement for Toyota's (and Ohno's) competence and appealed to the social scientists, industrial engineers, and consultants seeking a systematic explanation for Toyota's success. However, this encouraged observers to deconstruct the system as described (focusing on apparently key attributes such as *kanban* cards or *andon* boards etc.) and inevitably deemphasize the impact of 30 years of "trial and error." All systems analysis should take into account the specific history and context of that system, yet it is now so widely accepted that lean production was "born" in Japan, under the "parenting" of Taiichi Ohno, that crucial formative influences remain largely hidden from view. To illustrate this, operating innovations claimed by Toyota (Ohno, 1988: 95), such as laying out "machines in order of use," were widely employed in Ford plants of the 1920s (Williams et al., 1994).

See also jidoka; *just in time; JIT and MRP/ERP; JIT tools and techniques*; kanban; Seiri, Seiton, Seiso, Seiketsu, *and* Shitsuke

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## learning curves

*John Heap*

Learning curves are the functions that predict the reduction of labor input per unit of manu factured output. The concept can be applied at both micro and macro levels.

At the micro level when a worker is first trained to carry out a specific task, the perform ance on that task will naturally be poor. As the worker gains experience and develops the work specific skills, performance will improve. The rate at which such improvement is made will depend on a number of factors such as the com plexity of the work, the cycle time of the work, the ability of the worker, and his or her experi ence of similar work. However, in all cases, the rate of improvement will decrease over time as the worker becomes more proficient. A learning curve is a graphical representation of the im provement in performance and for most work follows a general asymptotic pattern. The graph normally relates performance (measured as job completion time) either to time on the job or to the number of job cycles completed.

Where WORK MEASUREMENT is used to establish the standard time for a job, it is possible to plot on the curve the desired end point of an induction or training period and to measure operator performance over time against this end point. Where a learning curve has been established by prior observation of a range of workers adjusting to the same work, it is possible to measure the progress of a new worker to the present time, and then to predict further rates of progress from the shape of the curve. Where a payment system based on individual perform ance is in use, it is common to add a "learner allowance" to the standard time to form an "allowed time" for a trainee. Similarly, where a payment system is based on team or group per formance, it is common to compensate the team for the poor performance of new members of the team. If learning curves are available for the work, any allowance or compensatory payments can be adjusted over time as the trainee moves along the curve.

At the macro level learning curves can be used to relate the total cost per unit (or value added per unit) to the cumulative output. At this level they are often called "experience curves." The relationship between COST and output usually assumes that costs decrease by the reciprocal of some function of cumulative output. This is often expressed as the amount cost decreases for each doubling of cumulative output. So, for example, an 80 percent experience curve means that costs reduce to 80 percent of their value when cumulative output doubles. For simplicity this relationship can be drawn on logarithmic scales, which will show a straight line relationship.

See also *double loop learning; time study*

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## leveled scheduling

*Alan Harrison*

It is sometimes beneficial to consider "leveling" scheduled material movements so that each movement is coordinated with the others when work cycles repeat. "Coordination" here refers to the timing and volumes of material movements and can be extended from the factory to suppliers and customers so that material movements are coordinated throughout the supply chain. Deploying the RUNNERS, REPEATERS, AND STRANGERS classification, runners and repeaters are prime candidates for leveled scheduling. Leveled scheduling is an important aspect of JUST IN TIME philosophy and plays a key role in the Toyota production system, where it is referred to as *heijunka*.

Leveled scheduling involves distributing volume and mix evenly over a given production time span. Output thereby matches customer demand as closely as possible at any instant during that time span. The development of leveled scheduling is illustrated in figure 1.

Suppose that we begin with a weekly production schedule for a range of three products, A, B, and C, which runs at 200 of product A, 120 of B, and 80 of product C. Assume that the customer for these products is using them evenly across the product range. Producing them in large batches according to weekly usage will create inventories of finished product and lead to production peaks that impose excessive work on one team at a time in preceding processes. Instead, it is better to level the finished product schedule as much as possible and to downdate that leveling to production of subassemblies and components as well. To begin, the batch sizes could be reduced to five of product A followed by three of product B followed by two of product C. But even greater leveling of "runners" can be produced by scheduling in the sequence AABABCABCA. This is called a mixed model assembly sequence and achieves maximum repetition in the shortest cycle. Mixed model assembly allows close tracking of changes to mix in demand for the products, and finished product inventory should be at a minimum. However, mixed model assembly is the most extreme approach to leveled scheduling in terms of setups. Therefore, it only becomes possible as SETUP REDUCTION leads to short setup times. Also, mixed model assembly places increased pressure on operators, who must cope with constantly changing product mixes. Use of error proof devices (*see* FAIL SAFING) to make it impossible to produce non conforming products therefore becomes a necessary feature of this approach.

Leveled scheduling places a number of demands on a production system. Operators

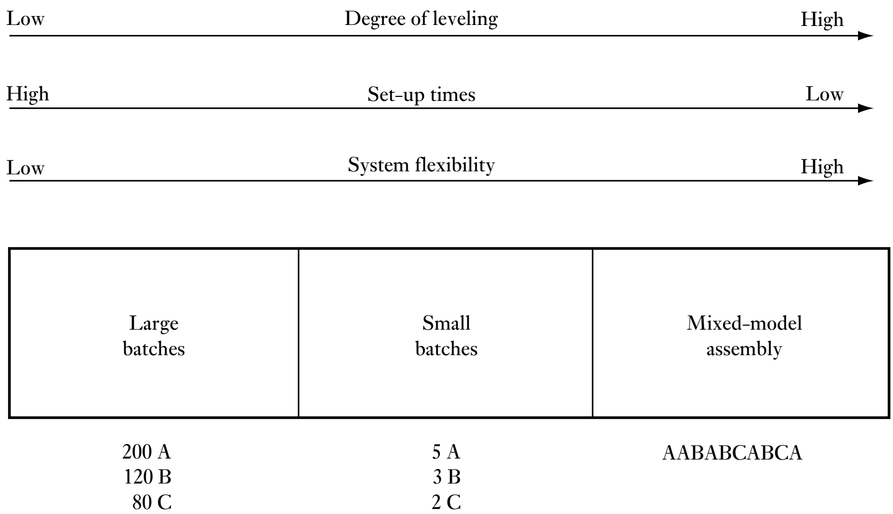


**Figure 1** Leveled scheduling

must be capable of switching quickly between different product mixes, transferring between areas of high demand and areas of low demand, and taking on different tasks. The processing capacity of each machine also needs to be har monized. A frequent temptation is to use the capacity of a machine to the fullest, but leveled scheduling principles indicate that the output of each process should be leveled to whatever is needed to produce the required output. This often means that machines are "derated," in as much as the output from them is deliberately reduced so that it is coordinated with other processes.

A related concept is that of the "band width" of a production system, which is a measure of its surge capacity to handle changes in volume and mix across a given range. If the objective of leveled scheduling is to be able to make any product in any sequence with no disruption, many processes need only to meet full surge capacity occasionally. Such processes are there fore usually run below capacity, and may often be shut down.

See also *JIT and MRP/ERP; sequencing*

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## life-cycle effects

*Michael Lewis*

The product life cycle model argues that a suc cessful product (i.e., one that achieves a reason able level of sales) will pass through several distinct stages in its total market life: introduc tion, growth, maturity, and decline. The gen eric, essentially linear, prescription derived from the model (developed in the 1960s and 1970s) is that products require different marketing, finan cial, manufacturing, purchasing, and human re source strategies at each stage of their life cycle. Correspondingly, one way of establishing the relative importance of operations objectives is to assess the life cycle stage of the product(s) being produced. This point is particularly im portant for all operations managers because it implies that operational objectives will and should evolve as a product matures.

- When a product or service is first introduced it is likely to be presented to the market on the basis that it is novel in some way. Because the number of customers is few and their needs are not well understood, the design of the product or service could be subject to frequent change. The operations manage ment of the company can best contribute to competitiveness by developing the FLEXI BILITY to cope with changes in the specifi cation of the product or service and possibly also in its output volume. At the same time, it will also need to maintain QUALITY levels so as not to undermine the performance of the product/service.
- If products survive their introduction to the market they will begin to be more widely adopted, and volume starts to grow. The design of the product or service could start to standardize. Supplying demand could prove to be the main preoccupation of or ganizations that have products or services in this part of the life cycle. Rapid and depend able response will help to keep demand buoyant, while insuring that the company keeps its share of the market as competition starts to increase (*see* DELIVERY DEPEND ABILITY; TIME BASED PERFORMANCE).
- After a period of rapid growth, products "mature." Demand starts to level off and the designs of the products or services may also stabilize to a few standard types. Com petition will almost certainly move to em phasize price or value for money, although individual companies might try to prevent this by attempting to differentiate them selves in some way. This increasingly price

conscious environment means that operations will be expected to improve its cost performance, either to maintain profits or to allow price cutting, or both. Therefore, COST and PRODUCTIVITY issues, together with dependable supply, are likely to be the operation's main concerns.

- When the product has been in the market for some time, the need that it was filling will eventually be largely met and sales will decline. For companies left with the old products or services there might be a residual market, but if capacity in the industry lags demand, the market will continue to be dominated by price competition. Operations objectives will therefore still be dominated by cost.

For firms operating in hyper competitive markets with very short product life cycles, the utility of such a model must be increasingly questioned. A firm such as Intel, for instance, must be ready with large scale production facilities from the very launch of a new microprocessor if it is to (1) meet demand and (2) make any profit before rivals rapidly respond with related product upgrades.

See also *manufacturing strategy; order winners and qualifiers; performance measurement*

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## line balancing

*David Bennett*

Line balancing is a technique used in connection with the design of PRODUCT LAYOUT or "lines." The term "balancing" is used because one of its main objectives is to minimize the idle time and spread it as evenly as possible across the workstations.

When balancing a line the following factors need to be taken into account:

- the required output rate or cycle time (which depends on the demand for the product);
- precedence constraints (these are restrictions on the order in which tasks can be done; in other words, certain tasks will have "predecessor tasks" that must be done first);
- zoning constraints (these are restrictions on where certain tasks or combinations of tasks should, or should not, take place);
- whether there is a need for workstation duplication or replication (this would be the case when any task takes longer than the available cycle time).

The line balancing problem comprises two aspects: (1) determination of the required number of stations and (2) the assignment of tasks to each station with the objective of maximizing efficiency (by minimizing idle time and spreading it evenly across workstations).

The effectiveness of the balance decision is measured by the "balance loss" of the line (*see* BALANCING LOSS). The balance loss is the time invested in making one product that is lost through imbalance, expressed as a percentage of the total time investment. For a paced *n* stage line, the time lost through imbalance is the cumulative difference between the stations' allocated work times and the cycle time allowed by the pacing of the line. For unpaced lines it is the cumulative difference between each stage's work time and that of the stage with the largest work time (this effectively governs the cycle time of the whole line) (*see* BOTTLENECKS).

A very simple line balancing problem may be solvable by "trial and error." Most practical problems, however, are extremely complex, requiring thousands of tasks to be assigned across hundreds of workstations and with numerous precedence and zoning constraints to be taken into account.

To solve such problems a large number of heuristic algorithms have been developed, such as the Kilbridge and Wester method and the ranked positional weights technique. Being based on heuristics, or "rules" that have been tested empirically, such techniques can provide good, though not necessarily optimal, results. More recently, simulation has grown in popularity as an approach to balancing lines and a visual interactive simulation can allow the line designed to immediately see the effect of any modifications made (*see* SIMULATION MODELING).

Product layouts have traditionally been used to produce highly standardized products, but today the demand is for a greater variety of products or models. Therefore two types of line are now in widespread use and require a modification to the traditional line balancing approach. These are multimodel lines, where the line is reorganized periodically to produce different models or variants, and mixed model lines, where the line is designed to allow simul taneous production of any model or variant without reorganization.

The aim in multimodel line balancing should be to minimize total production cost, taking account of the additional factor of changeover costs. For very large batches the problem degen erates into the successive application of single model line balancing.

The main costs of an operator changing from one product to another are connected with re allocation of inventory and equipment to work stations and LEARNING CURVES of operatives in new jobs. To reduce these costs, the number of stations and location of equipment should be constant whenever possible, and work elements common to more than one model should always be performed by the same operator. Since work content and production requirements vary be tween models, the cycle times are the best factors to manipulate in reducing idle time, but balan cing efficiency may be sacrificed for compatibil ity. The total balance loss will be the average per model, weighted in proportion to production ratios. A sensible ploy is to balance the line for the most popular model and to adjust this basic arrangement by empirical methods for the other models. If this is unsatisfactory, the steps may be repeated but centered on the model of second highest production volumes, etc.

For very small batches the problem is akin to the mixed model line. Here, achieving a good long term balance is more difficult and depends on the sequencing of model types proceeding down the line. One approach is to balance the line using a range of task times for each activity.

See also *business process redesign; layout*

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## Little's law

*Stuart Chambers*

Little's law is the mathematical relationship between throughput time in a process, the in ventory or work in process, and the cycle time of the process. It is stated as "throughput time equals work in process multiplied by cycle time."

The cycle time of a process is a function of its capacity. For a given amount of work content in the process task, the greater the capacity of the process, the smaller its cycle time. In fact, the capacity of a process is often measured in terms of its cycle time, or more commonly the recipro cal of cycle time, "throughput rate." So, for example, an automated bottling line would be described as having a capacity of a hundred bottles a minute, or a theme park ride as having the capacity of one thousand customers an hour. However, a high level of capacity (short cycle time and fast throughput rate) does not neces sarily mean that material, information, or cus tomers can move quickly through the process. This will depend on how many other units are contained within the process. If there is a large number of units within the process, they will have to wait in "work in process" inventories for part of the time (throughput time) that they are within the process.

Little's law is both simple and useful, and it works for any stable process. For example, if, in the case of a process with four stages and a cycle time of 12 minutes with space for one unit at each stage,

cycle time = 12 minutes
work in process = 4 units (one at each stage of the process)

then

$$\text{throughput time} = \text{work in process} \times \text{cycle time} = 12 \times 4 = 48 \text{ minutes}$$

See also *business process redesign; inventory management; P:D ratios; planning and control in operations; process mapping; time based performance*

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## location

*Roger Schmenner*

Industry location is the study of why manufacturing plants are located where they are.

Industry location is a topic of wide appeal. It is a central concern of economic development, and thus of local public policy. Clearly, historical accident, most notably involving the founder of the business, the initial market, or the location of particular raw materials, explains much of the general pattern of industry location. Of more acute interest is the work that has been done to isolate the factors that can attract new plants, either new branch plants or relocations, to particular locations. A rough consensus has emerged that financial incentives, typically tax breaks of one kind or another, are less effective in attracting new plants than more tangible incentives such as labor training or infrastructure development (new roads, sewers).

In the US, the single most important public policy relates to unionization of the workforce. Those states that do not permit the "union shop," where company–union agreements compel all employees to pay union dues, are at an advantage. These so called "right to work" states, where employees can refrain from paying union dues and thus act as free riders on whatever the union succeeds in negotiating with the company, are indisputable winners in attracting major manufacturing plants. Such a factor explains much of the shift of manufacturing in the US to states in the south and in the Great Plains and Rocky Mountains.

From the perspective of operations management, industry location is embedded in MANUFACTURING STRATEGY and how companies manage their capacity (*see* CAPACITY MANAGEMENT), and it is a multistage decision. For companies with growing capacity needs, the first stage decision is whether to expand on site. On site expansion is frequently pursued if there are no prevailing constraints such as physical limitations, aversion to size (many companies have informal limits to plant employment of 500 or 1,000 workers), or aversion to added complexity at the plant (too many product lines or processes). Only then are new branch plants seriously considered.

The new plant should fit into a prescribed place in the company's multiplant strategy. There are four major multiplant strategies: product plant, market area, process plant, and general purpose plant. With the product plant strategy, individual plants produce distinct products or product lines for distribution over wide geographic areas. The market area plant produces a wide variety of products but for a limited geographic area. The process plant concentrates on a particular segment of the production process, while the general purpose plant can undertake a wide variety of responsibilities.

Once it is decided to locate a new facility, and given the multiplant strategy that prevails, it is usually quickly deduced which factors are "musts" for the company and which are "wants." There are six primary "musts" that can control the location of manufacturing plants: labor costs, labor unionization, proximity to markets, proximity to supplies/resources, prox imity to other company facilities, and concern for the quality of life. Naturally, different kinds of companies are compelled by their economics and strategies to adopt different elements of these controlling concerns; there is typically little choice. Only when these controlling con cerns are addressed can the company turn to other concerns that are less important, but nevertheless sought after.

Relocations, the simultaneous or near simul taneous closing of one facility and opening of another, are rare events, more typical of small company growth than of large company decision making. The small, growing company seeks to keep its workforce together and moves nearby to larger quarters. Relocations within larger companies are usually only done as a last resort, to avoid location specific costs such as wages or taxes and to attempt to return the facility to profitability.

See also *global manufacturing network; industrial networks; international location; supply chain management*

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## logistics

*Simon Croom*

Logistics is the management of the materials and information flows throughout the supply chain. At a more detailed level, the US Council of Logistics Management defines it as "the process of planning, implementing, and controlling the efficient flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements." If "origin" is taken to refer to the original source of material, this def inition is close to one definition of SUPPLY CHAIN MANAGEMENT. If it refers to the ma terial and information flow associated with fin ished products, then it is close to PHYSICAL DISTRIBUTION MANAGEMENT. In both cases physical flows include raw materials and com ponents from suppliers into the organization and distribution of the physical outputs of the organ ization to customers. Logistics information flows are required to plan, coordinate, and manage the movement of physical resources.

The design of the logistics system is a funda mental aspect of supply chain management. In creasingly, organizations are attempting to use their SCHEDULING, INVENTORY MANAGE MENT, and distribution capabilities to provide the competitiveness of their customer service. One of the challenges in designing the logistics system is to insure that it provides the appropri ate levels of service for customers. Fisher (1997) argues that a key determinant in the design of the logistics system is the variability of demand for the product or service. In his seminal *Harvard Business Review* article he stated that where the demand for a product is stable and regular, it is appropriate to adopt a cost efficient logistics approach. On the other hand, where demand is highly variable, he stated that the logistics system will need to be "responsive" and consequently will have to be designed to support greater levels of schedule and production flexibility.

See also *materials management; vertical integration*

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## lot sizing in MRP

*Peter Burcher*

Lot sizing (or batching) in MATERIAL REQUIREMENTS PLANNING (MRP) is the process of modifying the net requirement quantities before they are translated into planned orders in an MRP system. If net requirements were translated directly into planned orders, it would result in manufacturing component schedules and purchasing schedules that did not take any account of the cost of machine setups or the cost of ordering. In other words, making the requirements as they occur on a period by period basis, otherwise known as the lot for lot policy, may certainly reduce overall stockholding costs, depending on the size of planning period chosen, but may increase costs incurred through excessive setup and ordering activities for small batches. To take account of the total costs of managing the materials, i.e., holding costs and ordering or setup costs, batch sizing rules or ordering policies may need to be applied to the net requirements to produce planned orders for the manufacturing or purchasing of items. There are basically three different groups of methods of batching requirements together.

### Fixed Quantity Batching

These rules essentially state that every time an item is manufactured or bought, it is done so in batches of minimum size $x$, or multiples of $x$. The fixed multiple batch size may be determined by a physical constraint of a manufacturing process, e.g., furnace or oven size, by considering the quantity that would normally be produced in one shift or in one week, or, most frequently, by the size of container that is used to transport the item. The minimum fixed quantity batch size is usually determined by some form of economic calculation. This could take account of price breaks or discounts for quantity, or it might use the so called ECONOMIC ORDER QUANTITY (EOQ) formula as used in traditional INVENTORY MANAGEMENT approaches. However, it should be noted that in an MRP system environment, the assumptions upon which the EOQ calculation is based are not valid, i.e., a continuous review inventory system is not in operation and there may not be continuous demand and a gradual depletion of the stock of the item. Consequently, although the EOQ may be a guide to the best batch size, it cannot be guaranteed that its implementation will result in minimizing total inventory operating costs.

### Fixed Period Coverage Batching

These rules calculate a batch size by batching together the net requirements for the next $y$ periods ahead. The coverage period may be chosen to fit in with a cycle scheduling approach to shop loading where, for example, machined components may be manufactured on a three weekly repeated cycle with one third of components starting in week 1, one third in week 2, and so on. If the choice is not determined by this constraint, an economic coverage period may be calculated by relating the EOQ calculation to an equivalent number of time periods' coverage.

Dynamic Batching Rules

A computer algorithm attempts to arrive at a batching schedule that minimizes inventory op erating costs. Dynamic rules include the following: least unit cost, least total cost (part period algorithm), McLaren's order moment, and Wagner Whitin. As an example, the least total cost (part period) algorithm consists of computing the cumulative holding costs and stopping at the batch size just short of the point where cumulative holding costs exceed the setup cost. It makes the cost comparison by first calculating the ratio of the setup cost to the holding cost per period, known as the part period value (PPV), i.e., how many parts may be held for how many periods whose holding cost will equate to the setup cost. For example, if the setup cost for an item was $500 and the holding cost was $0.3 per period, the PPV would be 500/0.3, which equals 1,667 part periods.

Each type of batching rule has its own advan tages and disadvantages. The fixed quantity rule is easily understood and may fit in well with manufacturing process constraints or suppliers' standard order sizes. However, it suffers from the drawbacks of generating orders at irregular intervals and, compared to the other methods of batching, it generates higher stock levels. In a non repetitive manufacturing environment it can also generate extra stocks that may become obsolete. Since the fixed period coverage rule is directly related to the future period's require ments, it is more economical in terms of the overall stock level generated and, as mentioned previously, it may fit in well with the balancing of the workload on the shop floor. However, it may result in sizes of batches that fluctuate con siderably, especially if there are periods with zero net requirements. Theoretically, the dy namic batching rules are superior to the other two methods of batch sizing in the reduction of costs. However, they suffer the disadvantages of not being understood as easily and of generating differing batch sizes at uncertain time intervals which, in turn, may lead to difficulties in shop loading.

See also *inventory control systems; inventory related costs; netting process in MRP; purchasing*

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# M

**maintenance**

*Michael Lewis*

Maintenance is the process whereby operations actively care for their physical assets and facil ities. Although often viewed as being of second ary importance in the strategic priorities of an organization, it can play a crucial role in insuring sustained operational performance. Specific benefits of maintenance for instance include:

- enhanced safety, in that well maintained facilities are less likely to behave in an un predictable or non standard way, or fail out right, all of which could pose a hazard to staff, customers, or other stakeholders;
- increased reliability, which in turn leads to less time lost while facilities are repaired, less disruption to the normal activities of the operation, less variation in output rates, and more reliable service levels;
- higher quality because badly maintained equipment is more likely to perform below standard and cause quality errors;
- lower operating costs since many process technologies run more efficiently when regularly serviced (*see* PROCESS TECH NOLOGY);
- longer lifespan of equipment because regular care, cleaning, or lubrication can reduce the (perhaps small) problems whose cumulative effect causes wear or deterioration.

In those operations where physical facilities/ assets are central to transformation processes and/or where safety concerns are paramount (e.g., power stations, hotels, airlines, petrochem ical refineries, etc.), maintenance activities typ ically account for a significant proportion of operations management's time, attention, and resources. Two principle metrics of maintenance performance are the "mean time between fail ure" (MTBF) and the "mean time to repair" (MTTR). MTTR is influenced by the ease with which facilities can be repaired, which includes such factors as ease of fault diagnosis, ease of access, and ease of repair or replacement. MTBF is influenced by the way in which facilities are used by staff and/or customers, the intrinsic robustness of the facilities design, and the care regime used for the facilities. Different ap proaches to maintenance take different views of the extent to which all of these factors come within the legitimate scope of the subject. In practice most organizations' maintenance activ ities will consist of some combination of three basic approaches.

- *Run to breakdown* (RTB): This policy allows facilities to continue operating until they fail. Maintenance work is performed only after failure has taken place. RTB is often used where repair is relatively straightforward (so the consequence of failure is small), or where regular maintenance is very costly (making preventive maintenance expensive), or where failure is not at all predictable (so there is no advantage in preventive mainten ance because failure is just as likely to occur after repair as before).
- *Preventive maintenance* (PM): This policy attempts to eliminate or reduce the chances of failure by servicing (cleaning, lubricating, replacing, and checking) the facilities at pre planned intervals. PM is used when the cost of unplanned failure is high (because of dis ruption to normal operations) and where failure is not totally random (so the mainten ance time can be scheduled before failure becomes very likely).

- *Condition based maintenance* (CBM): This policy attempts to perform maintenance only when the facilities require it. Some characteristic(s) of, for example, a produc tion line, such as vibration, would be moni tored and the results of this monitoring would then be used to decide whether an intervention is needed. CMB is used where the maintenance activity is expensive, either because of the cost of providing the mainten ance itself or because of the disruption that maintenance causes to the operation.

Each approach to maintaining facilities is appro priate for different circumstances. However, many operations adopt a mixture of these ap proaches because different elements of their facilities have different characteristics.

See also *condition based maintenance; fail safing; failure in operations; failure measures; pre ventive maintenance; reliability centered mainten ance*

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## make or buy

*David R. Probert*

The make versus buy decision is one of the most fundamental facing manufacturing and oper ations managers. It represents the choice be tween carrying out an activity within the organization or sourcing it from outside the or ganization. The activity to be sourced may be the manufacture of a particular component part of a product, a product complete in its own right, or simply a process or service that supports the business activity of the sourcing organization.

It can be seen from this wide spectrum of application that make or buy issues arise in just about every sphere of economic activity and are likely to have confronted managers for thou sands of years. Make versus buy assumes an increasing importance in the more developed economy, as the supply base grows more com plex and offers the choice of a greater range of specialist capability and services. Consequently, it is not surprising to find that this topic has been the subject of much research, comment, and advice as to good practice. Earliest references go back nearly 100 years, and in recent decades much has been published on this and related topics. Relevant fields of study and practice in clude supplier selection, supplier relationships, SUPPLY CHAIN MANAGEMENT, industrial economics (in particular transaction cost eco nomics), cost accounting, and many others. Each of these fields has a perspective on the make versus buy issue, all of which need to be integrated if a rounded consideration of the sub ject is to be made. A particularly useful concept is that of VERTICAL INTEGRATION, which comes out of the literature originating from the study of economics, industrial organization, and MANUFACTURING STRATEGY. The attraction of this concept is that it can be used to measure the degree to which economic activity is carried out inside or outside the firm.

The degree of vertical integration at which a company is operating can be quantified as the value added by the company as a percentage of its total sales. This measure differs significantly between companies operating in different sectors (e.g., oil and gas extraction versus con sumer electronics), but, more interestingly, en ables comparisons to be made between companies operating in the same sector but or ganized in different ways.

Much of the contribution to the field is anec dotal, providing interesting accounts of what has been successful or unsuccessful in particular cir cumstances. It is interesting to observe that what has proved successful – usually measured by the profitability of the organization making the de cision – has varied considerably over recent decades. The early years of the automotive in dustry were notable for the success of the Ford Motor Company, which developed a very high degree of vertical integration, carrying out a huge range of economic activity within its own organization. This included growing rubber trees and running sheep farms. In contrast, the most successful automotive companies at the end of the century concentrated on the design and final assembly of the vehicle, and outsourced many subassemblies and activities to the supply base. Consequently, their degree of vertical inte gration was much lower, although their profit ability remained healthy.

The importance of the subject arises not out of each individual decision but from the fact that, over a period of time, the consequences of all the decisions actually determine the size and nature of the whole enterprise. The definition of the boundary of the business is the fundamental consideration at the heart of make or buy, and the level of vertical integration of the company, and the range of technologically different activ ities conducted within its boundaries, will be the result of many past make or buy decisions.

In this context, it is reasonable to assume that a structured approach to make versus buy will enable better decisions to be made. This struc ture will include a long term context (make or buy strategy) in which individual make or buy decisions can be made, and some guidelines for the process whereby the decision should be made.

The fundamental question is to what extent a systematic approach to the make versus buy issue can be formulated. Is it possible for this decision to be made in a BEST PRACTICE manner? Dealing with these questions involves exploring the following topics:

- the context within which make or buy deci sions can be made effectively – i.e., the de velopment of a make or buy strategy;
- the factors that need to be considered in reaching a particular make or buy decision;
- the decision support process for the make versus buy decision.

These three aspects will now be examined. The discussion will focus on manufacturing industry where these ideas find their main application. However, the ideas are generally applicable and are readily adapted for use in other organiza tional environments.

### Developing a Make or Buy Strategy

This requires taking a long term view of what the business is aiming to achieve and is best carried out in the context of an overall strategic review. Make or buy at this level is at the center of a company's manufacturing strategy and rep resents a key structural decision area, along with factory size and LOCATION, and production processes. Infrastructural decision areas relate to new product introduction, human resources, production control, PERFORMANCE MEAS UREMENT, and quality systems (*see* QUALITY MANAGEMENT SYSTEMS). Decisions in all these areas need to be taken in a coherent manner if the business is to have a sound manufacturing strategy.

The strategic review necessary to develop a make or buy strategy should consider the following aspects:

- market position and trends;
- company product and process capability;
- customers, competitors, and suppliers – their characteristics, requirements, and cap abilities;
- cost analysis and comparison;
- projection of business results and sensitivity analysis.

Since the development of a make or buy strategy requires such a broad range of knowledge and perspectives, it is best conducted by a project team drawn from different functions within the business. These functions would typically in clude manufacturing, PURCHASING, finance, engineering, marketing, and LOGISTICS. A fur ther benefit of the multidisciplinary approach is realized when the strategy is implemented. Structural change such as that initiated by a make or buy review requires engagement from all affected parts of the business in order to be successful. If a number of people from different functions are involved in its development, they can act as advocates for the implementation.

During the process of analysis to explore the options for a new make or buy strategy, there are a number of decision support tools that can usefully be applied. Analysis focuses mainly on the component parts of a manufactured product, and on the manufacturing processes or technolo gies that are used to produce them. Decisions on whether or not to outsource any of these items are then driven by the impact on the busi ness results (usually determined by customer preferences), and constrained by the amount of investment the company can afford to make in skills, plant, and equipment.

A particularly useful analytical tool for prioritizing these choices is the competitiveness/importance matrix (see figure 1). Positioning component parts or process technologies on this matrix gives guidance as to the generic sourcing strategy that could be followed for a particular item (fuller guidance on the derivation and use of this matrix is given in Probert, 1997).

The business results of the overall choices should be modeled financially and tested for sensitivity in terms of how robust the results are when faced with varying market conditions. Since the strategy is likely to be projected over many months or even years into the future, this sensitivity analysis should consider the impact of varying conditions over this period. A good strategy will be one that can be projected to deliver acceptable business results over the planning period, taking into account the potential varying conditions.

The make or buy strategy gives long term guidance relating to manufacturing capability, but a further, more detailed analysis may be necessary when considering sourcing options for parts or processes that are positioned around the center of the matrix.

### Factors Relevant to Detailed Make versus Buy Considerations

Within the context of the overall make or buy strategy described above, there may be individual decisions that require more detailed analysis. In a manufacturing business, this could relate to individual component parts or production processes. Particular uncertainty may surround items located near the center of the matrix, and more detailed investigation is likely to be required.

The factors that need to be considered can be grouped into four main categories:

- technology and manufacturing processes;
- costs;
- supply chain management and logistics;
- support systems.

Each of these needs to be evaluated in detail in order to compare the viability of sourcing from inside or outside the firm. This implies compari

**Importance to business**

| Competitive position | High | Medium | Low |
|---|---|---|---|
| **Strong** | Continue to invest, maintain capability | Consolidate, keep pace | Licence/joint venture, reduce investment; or capability may open new market opportunities |
| **Neutral** | Invest, develop | Partnership | Stop, outsource |
| **Weak** | Initiate R&D, examine for investment or cease, find co-maker | Partnership | Stop, monitor, sell/licence, design out, find commodity supplier |

**Figure 1** The competitiveness/importance matrix

son with at least one potential supplier, which has been identified as a likely alternative source.

Technology and manufacturing processes concern factors that determine the organiza tion's ability to carry out a particular process effectively. This includes equipment and skills to perform and support the process, degree of ownership of the process, ability to cope with changes in volume, and achievement of defect rate targets.

Cost issues are central to make or buy evalu ation, but are often over emphasized. Because they are (apparently) easily quantifiable, they may assume dominance over less easily evalu ated, but equally important, factors. The cost factors under consideration must include the total cost of introducing the item under evalu ation into the supply chain. These are both pro duction costs and, for bought in items, the acquisition costs. At the same time that cost comparisons are over emphasized, acquisition costs are often overlooked. This is because some of the elements within acquisition costs may not be very obvious. They include trans portation, inspection, duty, and legal, purchas ing, and contract costs.

Cost comparisons with other organizations are very difficult to make objectively and accurately. This is because, even if the basis of the in house costing system is well understood and accurate, it is unusual to have a clear view of the cost structure in another organization. Good practice in purchasing involves understanding the cost base of the supplying company, but in reality decisions are very often made on the basis of quoted price. Apparently attractive supplier price advantages often assume less significance when other difficulties arise, e.g., delivery prob lems or unexpected acquisition costs.

Supply chain management and logistics cover factors affecting the effective operation of these functions, such as supplier selection procedures, cost reduction activities and collab orative programs with suppliers, delivery per formance, achievement of stock targets, and inventory control (*see* INVENTORY CONTROL SYSTEMS).

Support systems include factors that relate to the business infrastructure that contribute to the control and improvement of the production process, e.g., quality systems, CONTINUOUS IMPROVEMENT practices, training schemes, engineering changes systems, and technical sup port systems.

It can be seen from the breadth of information required, that preparing for such a decision is a significant undertaking. As with the strategic evaluation, it is best carried out by a project team following a systematic process. In addition to helping with the implementation, there is some experience and skill that can be developed within the team that assists the decision process. This is particularly important as individual de cisions are likely to be made more frequently than strategy is developed.

## Make or Buy Decision Support

Although many organizations recognize the im portance of make or buy strategy and decision making, survey work has shown that it is a mi nority that have put systems and resources in place to deal with it. Many still address the issues in an ad hoc manner and risk the inconsistency of outcome described earlier. There are, however, a number of comparatively simple techniques and routines that companies can put in place to sup port the decision process and minimize the "re inventing the wheel" syndrome.

In addition to the matrix analysis described above, the strategy development is often sup ported by a make or buy decision tree. This is a representation of the key choices and can be used to guide the project team to the most appropriate sourcing option. The criteria relevant to the current overall business strategy can be embed ded in the decision tree. A generic example of such a decision tree is shown in figure 2. It can be seen that there is typically a key turning point in such decision trees, in this case the question "Is the item of strategic importance?" Answering this question is of course the key issue. The criteria to resolve it are drawn from the business strategy and business objectives and are linked to the factors determining the position on the im portance scale of the competitiveness/import ance matrix.

In addition to the decision tree, multi attri bute decision support techniques can be useful to support the evaluation of choices arising from the more detailed analysis discussed above. In this process the project team can assign weight ings and scores to the various factors that come

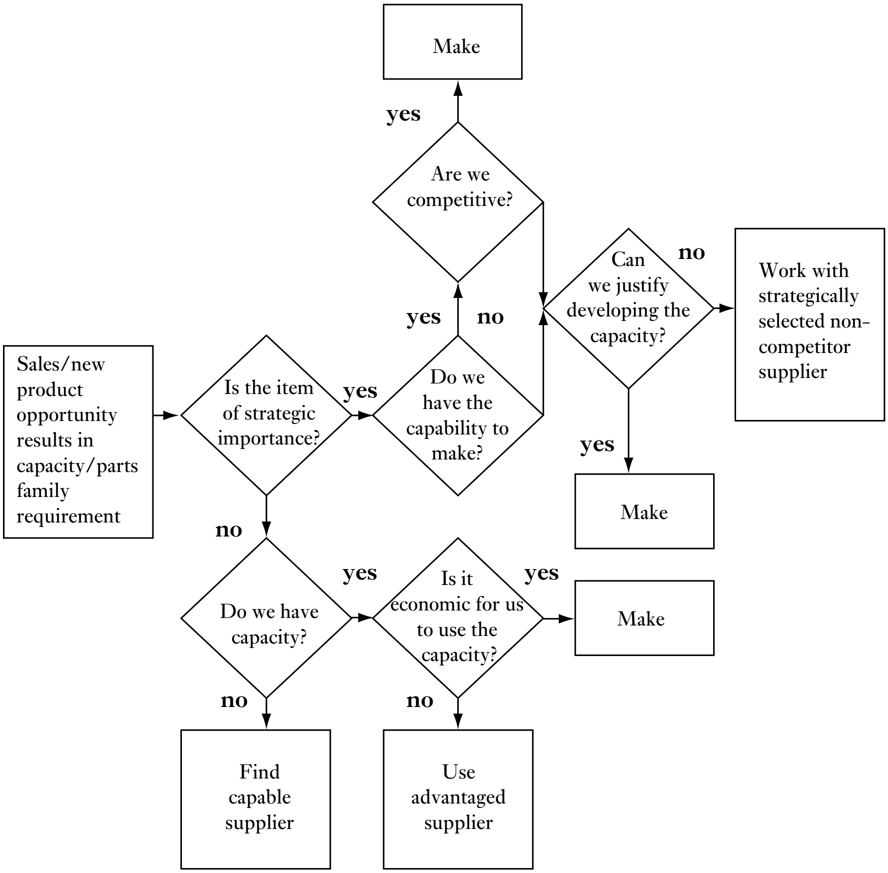


**Figure 2** Typical make versus buy decision tree

into the analysis. It would be misleading to sug gest that such techniques can lead to the un equivocal "one right answer," but they do provide the means to trace the decision process, balance arguments, and carry out sensitivity an alysis on the outcome (a typical process is de scribed in detail in Canez, Platts, and Probert, 2001).

In conclusion it can be safely stated that make versus buy strategizing and decision making is never complete. Evolving markets and technol ogy drive the need to constantly review how an organization can best add value, please the cus tomer, and make a profit.

See also *outsourcing; structural and infrastructural decisions; supply management*

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**manufacturing resources planning**

*Peter Burcher*

Manufacturing resources planning (MRPII) is a structured approach to manufacturing manage ment in which an integrated business system is used for the effective closed loop planning of all the resources of a manufacturing company. It is a direct outgrowth of CLOSED LOOP MRP, which in turn is an extension of MATERIAL REQUIREMENTS PLANNING (MRP).

It is made up of a variety of functions, each linked together, sharing much information on a central common database. These functions in clude all those incorporated in closed loop MRP such as business planning, sales planning, production planning, resource requirements planning, MASTER PRODUCTION SCHEDULE, rough cut capacity planning, MRP, capacity re quirements planning, input–output control, SCHEDULING, and dispatching. The extra functions that are included in MRPII are pri marily the commercial, financial, and costing systems such as sales order processing, invoi cing, purchase, sales and nominal ledgers, standard costing, actual product costing, and estimating/quoting.

MRPII systems provide information that is useful to all functional areas and encourage inter departmental interaction. MRPII supports sales and marketing by providing an order promising capability. This allows sales staff to have accurate information on product availabil ity and gives them the ability to provide custom ers with accurate delivery dates. MRPII supports financial planning by converting material schedules into capital requirements. MRPII can be used to simulate the effects of different master production schedules on mater ial usage, labor, process capacity, and capital requirements. MRPII provides the purchasing department with long range planned order re lease schedules for developing long range buying plans. Data in the MRPII system are used to provide accounting with information on material receipts to determine accounts payable. Shop floor control information may be used to track workers' hours for payroll purposes.

Other reports that can be produced from MRPII systems include full product costings at standard or actual cost, profit plans, cash flow plans, costed purchase commitments, shipping budgets, and inventory projections in value terms. MRPII can be viewed as a total approach to managing a business.

Over the years much has been written and a lot of research has been carried out into the reasons for success and failure in the implemen tation of MRPII systems. Among the main con clusions drawn is the need for a thorough understanding of the philosophy and discipline underlying MRPII, top management support, maintaining stability around the implementa tion, and committing resources to support education and training. The Oliver Wight or ganization, which specializes in MRPII educa tion and consultancy, developed an ABCD checklist in order to provide a universal measure of success in MRPII implementation. The ori ginal ABCD checklist was a questionnaire covering some of what the Oliver Wight organ ization considered to be the key aspects of MRPII. These included the functionality of the software being used, the accuracy of the data held within the system, the way in which man agement was using the system, the extent of the training program undertaken, and a selection of operational performance measures. A grade was awarded to the company depending on the answers given. The ultimate accolade was to achieve Class A status.

See also *computer integrated manufacturing; en terprise resources planning; JIT and MRP/ERP; material requirements planning*

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**manufacturing strategy**

*Chris Voss*

The need for manufacturing decisions to be made in a strategic context has been recognized for many years. The first developments in what is now known as manufacturing strategy took place at Harvard in the 1940s and 1950s. Re searchers started looking at industries and began to see that there were many different ways in which companies were choosing to compete within particular industries. These in turn were accompanied by different choices concerning production technology and production manage ment. From this developed a series of industry based casebooks. These contained notes on the industry and its technological choices as well as case studies of different companies in the indus try. Success and failure could be explained in many cases by the choices that the companies made and the alignment of these choices to com petitive strategies. In many ways these early manufacturing strategy approaches presaged the development of the industry based strategy approaches of economists.

Vital to the widespread dissemination of manufacturing strategy as a key area of concern was the pulling together of the lessons learned in this industry based study and teaching. This was done by Wickham Skinner in two seminal articles (Skinner, 1969, 1974). The first article set out the importance of explicit linkages be tween manufacturing choices and the firm's en vironment and corporate strategy. The second article developed the concept of FOCUS and of internal as well as external consistency. The framework in the 1969 article was very thorough and much subsequent work has focused on parts of the framework, simplifying and explaining rather than expanding.

A common way of viewing manufacturing strategy has been to separate the process of manufacturing strategy formulation from the content of manufacturing strategy.

Since the early work of Skinner, writing and practice in manufacturing strategy has de veloped on several different fronts. The first of these can be characterized as competing through manufacturing. This is achieved through aligning the capabilities of manufacturing with the competitive requirements of the market place. The second is the approach based on internal and external consistency between the business and product context and the choices in the content of the manufacturing strategy. This is effectively a contingency based ap proach. Finally, there are approaches based on the need to adopt BEST PRACTICE, character ized by, for example, "world class manufactur ing." We will explore each of these in turn.

### Competing through Manufacturing

At its simplest, this approach to manufacturing strategy argues that the role of manufacturing in competitive strategy is that the firm should com pete through its manufacturing capabilities and should align its capabilities with the key success factors, its corporate and marketing strategies, and the demands of the marketplace.

The theme of deciding "how we are to com pete" recurs repeatedly in many forms in manu facturing strategy literature. Cost, quality, dependability, and flexibility (*see* OPERATIONS OBJECTIVES) have become widely used as statements of the competitive dimensions of manufacturing. One of the best formulated ap proaches is that of Hill (1993), who developed the concept of ORDER WINNERS AND QUALI FIERS. His "order winning criteria" include price, delivery, quality, product design, and var iety. Similar sets of criteria or priorities have been developed by most writers in manufactur ing strategy. Hill also argues that although com panies "win orders" based on particular criteria, this does not mean that other criteria are not important. He develops the idea of "qualifying" criteria, performance criteria that a company must meet if it is to be in a market, even if they do not win orders. He suggests methodologies for identifying order winning and qualifying cri teria. The choice of competitive priorities and international comparisons of different countries has also been widely studied. Such approaches are consistent with the business strategy con cepts of writers such as Porter. His generic strat egies – cost leadership, differentiation, and focus – can be considered as business priorities directing manufacturing choice and manage ment. A number of authors have defined GEN ERIC MANUFACTURING STRATEGIES; one such group comprises cost, technology, and market driven strategies; others have developed taxonomies of manufacturing strategies.

The underlying argument of this paradigm is that aligning the capabilities of manufacturing with the key success factors will maximize the competitiveness of a firm. This can involve, for example, choosing manufacturing technology to achieve particular desired capabilities, or developing capabilities to develop and launch new products rapidly.

Hayes and Wheelwright (1984) propose a four stage development of a business' ability to compete through manufacturing. To be able to do this, they argue that companies should go beyond looking to align capabilities with the marketplace. Manufacturing should seek to influence corporate strategies and to proactively develop and exploit manufacturing capability as a competitive weapon.

There has been wide ranging work on identification, development, and measurement of manufacturing capability. For example, there has been much attention to the area of time based competition, and the technologies and capabilities to achieve it. Others have examined the role of flexibility in manufacturing. More recent work has tried to link the views of manufacturing capability with resource based theories of strategy (Powell, 1995).

A further element of this paradigm is the argument that through clear articulation of corporate missions and strategies, a company's vision will be shared by its managers and other employees. In the manufacturing area, this approach is frequently espoused in the quality literature. For example, the Malcolm Baldrige National Quality Award and the European Quality Award both emphasize the role of leadership in creating a shared vision (*see* BUSINESS EXCELLENCE MODEL), and the concept of "policy deployment" is used to describe this process. A shared vision is not confined to quality but can encompass a wide range of capability and market dimensions.

## Strategic Choices in Manufacturing Strategy

The second paradigm is based on the need for internal and external consistency between choices in manufacturing strategy. Skinner (1969) proposed that the key choice areas in manufacturing strategy consisted of plant and equipment, production planning and control, labor and staffing, product design and engineering, and organization and management. These are commonly considered in terms of two sets of choices: process (or "structure") and infrastructure (Hill, 1993). These are in effect contingency based approaches as they argue that choices made are contingent on context and strategy. Many other authors have followed this approach.

A central concern has been the choice of manufacturing process, first put forward by Hayes and Wheelwright (1984) in their PRODUCT PROCESS MATRIX. They viewed process in both a static and a dynamic mode. In a static mode they argued that the choice of process was contingent on the context of manufacture, in particular the VOLUME and VARIETY. They showed how misalignment could lead to poor manufacturing and business performance. They also argued that as markets evolved and changed, so too did the required process. Finally, they also related this to more complex environments such as multiprocess, multiproduct environments where there was a need for focused plants.

The process choice concept has been taken and developed by many authors, and taxonomies of process have been developed relating the newer manufacturing technologies such as the flexible manufacturing cell (FMC) and FLEXIBLE MANUFACTURING SYSTEM (FMS) to the traditional processes used by Hayes and Wheelwright. From this has developed the concept of mass customization. Pine, Victor, and Boynton (1993) argue that process is not only a choice but there is also an optimal route from one process to another. Process choice is not confined to manufacturing process but can be extended to include choices of processes and infrastructure in engineering. The strategic choice paradigm is essentially a contingent approach, with many authors using terms such as internal and external consistency. Hill's approach in particular has a strong contingent basis. He argues that choice of process is dependent on both the market strategy (expressed in similar terms to Hayes and Wheelwright's volume and variety) and the order winning criteria.

Strategic choices also apply to infrastructure. Hill (1993) argues that all the other (infrastructure) choices are contingent on the choice of process. A number of authors have examined the relationship with manufacturing strategy of various individual infrastructure areas such as manufacturing planning and control systems, middle management, and organizational culture. These approaches naturally lead to the operationalization of the concept of focus. They define for a given context the dimensions and choices on which a factory should be focused.

In summary, the paradigm based on strategic choices is based around the need to attain internal and external consistency and is a contingency based approach. Failure to match with external business, product, and customer factors can lead to a mismatch with the market. Also emphasized is the importance of internal consistency between all the choices in manufacturing. Failure in this aspect can result in a mismatch between the various choices in manufacturing that will severely impair a company's ability to be competitive.

### Best Practice

Best practice is probably the most recent of the three paradigms to become prominent in manufacturing strategy, though it can be argued that concern for best practice has been with humankind ever since the emergence of the first craft in prehistory.

In recent years writing on best practice has been dominated by Japanese manufacturing practice. However, best practice has come from many sources: MATERIAL REQUIREMENTS PLANNING (MRP) from the US, OPTIMIZED PRODUCTION TECHNOLOGY (OPT) from Israel, FMS from the UK, group technology from Russia, to name but a few. In recent years best practice literature has included JUST IN TIME manufacturing, which has evolved into LEAN PRODUCTION, TOTAL QUALITY MANAGEMENT, and CONCURRENT ENGINEERING. This approach is supported by research that shows strong linkages between adoption of best practice and operating performance. Companies with best practice perform better than those without.

Three particular stimuli have brought best practice to greater prominence. The first has been the outstanding performance of Japanese manufacturing industry. This has led to a continuous focus in the West on identifying, adapting, and adopting Japanese manufacturing practices. The second is the growth of business process based approaches and BENCHMARKING. This has led companies to identify their core practices and processes and to seek out best in class practice. Finally, there has been the emergence of awards such as the Malcolm Baldrige National Quality Award and the European Quality Award. These have brought a high profile to best practice in certain areas.

Much of the best practice school of manufacturing strategy has been brought together in the concept of "world class manufacturing." This is commonly taken to be the aggregation of best practice in a wide range of areas of manufacturing. The concept of competing through world class manufacturing was developed by Hayes and Wheelwright (1984) and the term was widely adopted after the publication of Schonberger's (1986) book. World class can be seen as having best practice in areas such as total quality, concurrent engineering, lean production, manufacturing systems, LOGISTICS, and organization; and in achieving operational performance equaling or surpassing best international companies.

The underlying assumption of this paradigm is that best (world class) practice will lead to superior performance and capability. This in turn will lead to increased competitiveness. To summarize, this paradigm focuses on the continuous development of best practice in all areas within a company. Failure to match industry best practice can remove the competitive edge from manufacturing.

### The Three Paradigms

Each paradigm has a particular set of strengths and weaknesses. The competing through manufacturing approach can lead to very high visibility for manufacturing strategy in an organization. The visible focus on competing on a limited coherent set of factors can be a uniting force within an organization. It can lead to employees and managers sharing a common vision and has the potential of creating a debate between manufacturing, marketing, and corporate strategists. The focus on capability can lead to management attention being paid to the development and exploitation of competitive capabilities in manufacturing, potentially leading to Hayes and Wheelwright's stage four.

There are, however, questions and limitations. If not carried out properly, this approach can lead to just a bland mission statement. If not backed up by consistent decisions and action, it risks leading to little more than management by rhetoric. It is also clearly not sufficient for development of a complete manufacturing strategy. No matter how good the focus and commitment of the company to meet a particular goal, it will fail if there are inappropriate processes or a misaligned infrastructure. Unbounded choice has also been questioned by several authors. In particular Ferdows and de Meyer (1990) propose that there is a natural sequence of priorities. They describe this in the SANDCONE MODEL OF IMPROVEMENT. They argue that there is a need to build a strong foundation of quality before proceeding to focus on other priorities.

Strategic choice is potentially the most powerful of the manufacturing strategy approaches. It can provide a clear view of a wide number of choices that a company has. Its contingency based approaches can lead to matching the whole of the operations strategy to the market positioning. This can result in strong internal as well as external consistency. To succeed it requires an effective process of manufacturing strategy development, which can be difficult to install. However, once developed it can not only put manufacturing on the top management agenda, but also embed strategic approaches to manufacturing within a company. The correct choices can lead to focused manufacture, from which superior performance will be derived. However, it can be argued that it is possible to have internal and external consistency in manufacturing without having good practice. Consistency approaches do not in themselves lead to the adoption of new and different practices. As a result, step changes resulting from this may be missed.

The visible success of Japanese companies has led many companies to seek best practice as the basis of their manufacturing strategies. However, the evidence is that this can cause major problems, particularly in companies that are far from best practice. First, best practice usually comes in small, isolated pieces such as just in time, MRPII, FMS, TQM, concurrent engineering, and business process reengineering. These approaches are often used in an isolated manner by companies. In addition, they are often treated as the means of solving all of a company's problems: "if only we had this we would become competitive." There is often a lack of perspective. Questions such as "is this appropriate for us?" and "would adoption support our key competitive needs?" often fail to be asked. Research has shown that there are sharp differences between companies and countries, with some having most good practice in place, and others with relatively little. For those already with substantial good practice, searching for and incrementally adopting best practice becomes a routine task. However, for those far from best practice, the problems are compounded by difficulty in knowing where to start. A firm will have limited capability to adopt new practices. The question of "what will we do first?" will dominate. It is for these companies that linking programs of adoption of best practice to competitive needs becomes crucial. Another agenda in best practice approaches becomes implementation. Best practice will not by itself guarantee improved performance. All reports of best practice show that there is a substantial failure rate in the implementation of each practice.

The three different paradigms should not be treated in isolation, and indeed many authors and experts bring at least two of them together. There are clear links between "competing through manufacturing" and "strategic choices" approaches. Hill directly links priorities (order winning criteria) to contingency approaches (choice of process) and sees them as a single linked framework. For example, competing on cost leads to a particular process choice and in turn infrastructure. Writers on flexibility and mass customization also stress the link between process choice and competitive priorities.

Similarly there is also a clear link between competing through manufacturing and best practice. Hill implicitly argues that best practice programs should be matched to order winning criteria. However, the implicit assumption that priorities and hence manufacturing tasks are orthogonal has been questioned. The relationship between quality and costs is a good example. Increasingly, quality is now recognized as a major contributor to cost reduction. Thus in a cost competitive environment, quality programs may be the most appropriate response rather than cost reduction programs. Empirical evidence from Japanese companies suggests that the best companies have very high productivity and high quality and that these companies also have fast product development times. Writers have questioned whether this means that TRADE OFFS in manufacturing strategy no longer exist. On the one hand, the traditional trade offs such as cost versus quality are no longer valid. On the other, it is difficult to be best in class in a large number of criteria simul taneously.

The link between best practice programs and strategic choice is less clear. First, there is the issue of whether some best practices are univer sal and, as such, are independent of context. Proponents of TQM would strongly argue this. On the other hand, some "best" practices such as KANBAN or MRPII are clearly not applicable in certain contexts. The phrase "best in *class*" frequently used in benchmarking may reflect the need to link best practice to context or "class."

The above discussion has focused on the dif ferent paradigms of content of manufacturing strategy. The process of manufacturing strategy formulation is equally important as content. Until recently, most attention had been paid to the content rather than the process of manufac turing strategy.

PERFORMANCE MEASUREMENT is a con cern that underlies different manufacturing strategy paradigms. It has frequently been argued that measurement must match the com pany's strategic needs, and to respond to this "balanced scorecard" approaches have been de veloped. The study of manufacturing strategy has developed in the context of single countries. Increasingly, manufacturing strategy must be set in the context of global business. Manufacturing process and infrastructure choices must reflect the additional set of economics and issues arising from managing in multiple countries. These must in turn reflect the local culture, resources, and practices.

All three paradigms of manufacturing strategy have their strengths and weaknesses and each partially overlaps the other. Any company needs a strategic vision as without one the other actions may fail. This is the logical starting point and needs to be revisited at regular inter vals. The strategy for competing through manu facturing will lead to the need to make key strategic choices. These in turn will require the development of world class performance in the areas chosen and, by necessity, the development of best in class practices. The choice and focus of these will be guided in part by the previous approaches. The CONTINUOUS IMPROVE MENT and development of process and practice will lead to developing the company's capabilities. These in turn may enhance or change the way it chooses to compete through manufacturing.

See also *business process redesign; content of oper ations strategy; flexibility; manufacturing strategy process; operations role; planning and control in operations; self assessment models and quality awards; service strategy; structural and infrastruc tural decisions*

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## manufacturing strategy process

*Ken Platts*

The process of manufacturing strategy formula tion is concerned with the way in which organ izations determine the objectives of their manufacturing function, the manufacturing re sources that are required, and the methods of coordination and control of those resources. It is one of the key tasks for operations managers, yet the process is extremely complex. There are many approaches to strategy formulation, but most find their roots in the rational view of the strategy formulation process developed in the 1960s and 1970s by, among others, Ansoff (1965) and Andrews (1971). The approach is essentially prescriptive, analytical, and rational. It specifies how strategies should be consciously formulated. Hofer and Schendel's seven stage model (Hofer and Schendel, 1978) succinctly summarized this, laying out in overview the steps that organizations need to undergo.

The first three steps were essentially auditing the current situation: step 1 was the identifica tion of current strategy; step 2 was an identifica tion of opportunities and threats; step 3 was an assessment of the principal skills and resources available. The next step was the pivotal step, a "gap analysis," which involved the comparison of the organization's objectives, strategy, and resources against the environmental opportun ities and threats to determine the extent of change required in the current strategy. Step 5 was the identification of the options upon which a new strategy might be built, followed by step 6, evaluating these options to identify those that best met the values and objectives of all stakeholders, taking into account the environ mental opportunities and threats and the re sources available. The final step (7) was selecting the most appropriate options for im plementation.

The rational "gap methodology" has under pinned most formal planning approaches to strategy formulation. However, when the pro cess of strategy formation is observed in practice, other modes of the strategy making process can be seen. Mintzberg (1973) identified two further modes, the entrepreneurial mode, a strong leader controlling the organization, and the adaptive mode, the organization adapting in small disjointed steps. Mintzberg (1978) ob served the processes of strategies emerging rather than being deliberately planned. Strat egies can form as well as be formulated; they can emerge in response to evolving situations. He introduced the definition of realized strategy as a pattern in the stream of actions: "strategies as ex post facto results of decisional behavior."

This descriptive view of strategy formation is in marked contrast to the previous formalized planning view. In practice, both aspects come together to give a complete view of strategy formulation, but it is only the planning approach that can be directly controlled by managers. Quinn (1978) acknowledged a role for the classic, formal planning techniques. They provide a dis cipline forcing managers to take a careful look ahead periodically; require rigorous communi cations about goals, strategic issues, and resource allocation; stimulate longer term analyses than would otherwise be made; generate a basis for evaluating and integrating short term plans; lengthen time horizons; and create an informa tion framework.

## Manufacturing Strategy Process in Detail

*Defining strategy.* Before looking at a manufacturing strategy process, it is necessary to understand what a manufacturing strategy needs to encompass. A review of the literature shows that most writers see manufacturing strategy as consisting of a set of manufacturing objectives which support business objectives, and a set of policies, decisions, and actions aimed at achieving those objectives. More formally:

> A manufacturing strategy is defined by a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate in order to meet a set of manufacturing objectives which are consistent with the overall business objectives. (Platts and Gregory, 1990)

*Outline of a process.* A strategy process needs to guide its users through the steps of determining the objectives for manufacturing, assessing the extent to which these are being met, and then developing courses of action to close the gaps between current and desired performance. The similarity with the Hofer and Schendel model referred to earlier will be noted.

There is an implicit process in the strategy frameworks of Skinner (1969), Wheelwright (1978), Hayes and Wheelwright (1984), and their derivatives. This implicit process depends on breaking manufacturing down into a number of decision areas and making the goals of manufacturing explicit in terms of a number of performance criteria. The steps of identifying these criteria, prioritizing them, and relating the decision areas to them form the basis of the process.

One of the most widely known strategy formulation procedures is that developed by Hill (1993). His process comprises five stages: understanding the corporate objectives of the organization; understanding the marketing strategy of the organization as it derives from corporate objectives; determining order winning and order qualifying criteria (*see* ORDER WINNERS AND QUALIFIERS); identifying the appropriate process choice for the manufacturing operation; and determining the relevant infrastructural choices. The choices in the last two steps are conditioned by the order winning and qualifying criteria, determined in step 3. It is widely accepted that step 3 is the defining step in this process. It involves asking the question, "how do products win orders in the marketplace?" From the answer to this question, the objectives imposed on manufacturing are identified. These are usually expressed in terms of COST, QUALITY, delivery speed and reliability (*see* DELIVERY DEPENDABILITY), and FLEXIBILITY. Although primarily a "top down" process, Hill did not intend it to be a simple, sequential movement from step 1 through to step 5, but rather an iteration involving both marketing and manufacturing jointly developing a competitive position in which each supports the other. The process produces two outputs: a statement of the implications for manufacturing of future market projections, and an understanding of the way in which the capabilities and resources of manufacturing can themselves influence the strategic direction of the organization as a whole.

More recent work on manufacturing strategy formulation processes has been carried out by the team at the University of Cambridge. The first Cambridge process, published through the UK Department of Trade and Industry (DTI, 1988), was based on an audit approach (Platts and Gregory, 1990). This involved identifying different PRODUCT FAMILIES within the business, identifying their competitive criteria and comparing the achieved performance with these, and then going on to investigate the existing practices that led to the gap between achieved and required performance. The final stage was to develop alternatives, which would lead to a better match and form the basis for a revised strategy. It can be seen that this followed closely the traditional "gap" methodology; however, it was customized for manufacturing and incorporated the ideas of Hill's order winning and qualifying criteria. It went beyond this, however, to audit the capabilities of the manufacturing operation in order to identify both current operations practices and the impact of these practices on performance. This recognizes that there are two aspects to strategy process: the market based view and the resource based view. For several years there was academic debate about the relative merits of each, but it is now becoming widely accepted that both perspectives are essential in developing a comprehensive strat egy. The market based view insures that manu facturing's objectives are aligned to the needs of the market, while the resource based view is concerned with the development and coordin ation of manufacturing resources to provide spe cific competences, or capabilities, that will support, or provide, competitive advantage (*see* COMPETENCE).

Later work by the Cambridge team has in corporated more explicitly both perspectives resulting in a more comprehensive process, em bodied in two books (Mills, Platts, Bourne, et al., 2002; Mills, Platts, Neely, et al., 2002). The first book explores the ways in which resources can build into manufacturing capabilities, while the second describes in detail an essentially market based approach to manufacturing strategy formulation.

### Implementing a Manufacturing Strategy Process

So far, strategy process has been discussed in terms of a sequence of steps to be undertaken, i.e., a procedure. However, research has shown that other characteristics are required for a suc cessful process. Platts (1994) has termed these the 4Ps: procedure, participation, project man agement, and point of entry.

*Procedure.* There should be a well defined procedure to progress through the stages of gathering information; analyzing information; and identifying and choosing strategic alterna tives. The procedure should incorporate simple and easily understood tools and techniques. Op erational managers feel more comfortable when they can see the overall structure of the process and appreciate how the individual pieces fit to gether. They like to understand any techniques that are used and need to be able to relate these to their own experience. There should be a written record of the results at each stage, both to force closure and to insure that data and assumptions can be revisited at future dates. This will be useful both at subsequent formal strategy reviews and, more importantly, as a strategic management tool that can be used to assess the likely impact of changes in the business environ ment or incremental policy changes. As dis cussed in the introduction, descriptive studies have shown that strategies can evolve incremen tally, yet formal planning followed by imple mentation, as suggested by the traditional prescriptive strategy models, does not fully take account of this. By referring to a record of the results of the previous application of the strategy methodology as circumstances change, manage ment teams can insure that their strategies evolve in a way that is likely to lead to internal and external consistency of decisions taken.

*Participation.* The traditional view of strategy formulation embraces the idea of the brilliant strategist, working alone, contriving a grand plan in much the same way as the great army commanders of history. Indeed, the very word "strategy" is derived from the Greek word for "the art of the general." This is not an appropri ate model for manufacturing strategy formula tion. Because manufacturing strategy is an integral part of a business strategy and because successful implementation is more likely if the strategy is widely accepted, there needs to be involvement throughout the strategy formula tion process. There should be individual and group participation to achieve enthusiasm, understanding, and commitment. This can often be achieved through workshop style inter pretation meetings to collectively agree ob jectives, identify problems and develop improvements, and to catalyze involvement. The use of GROUP WORKING, particularly in volving multifunctional groups, is important as it offers many benefits both in improving the quality of the decision making process and in developing a sense of ownership of the outcome.

Most strategy formulation methodologies are based on data to answer questions such as "where are we now?" Because these data are fundamental to the outcome of the process, it is necessary to cross check such data early in the process. The use of multifunctional groups pro vides such a mechanism. It provides inputs from different functions within a company and sup plies expertise that can be pooled to aid the entire group. The diverse range of knowledge and access to information of such a group usually enables many misconceptions and data errors to be identified. The use of structured group working insures that key issues are adequately discussed and their implications explored before decisions are made. By seeking to achieve consensus at each stage of the process, participants are taken logically toward a conclusion based upon information and discussion rather than on prejudice.

Finally, a participative approach insures that company personnel are closely involved throughout the process and will therefore "own" the strategy developed. This is one of the most important aspects of participation in the methodology. A strategy only shows any effects when it is implemented, and developing a sense of ownership within the participants should facilitate any downstream implementation activity.

*Project management.* As with any project, the strategy formulation process must be adequately resourced and work to a time scale (*see* PROJECT MANAGEMENT). The resourcing must comprise three types: managing resource, the company personnel taking responsibility for the project; supporting resource, the internal or external personnel providing the process "expertise"; and operating resource, the personnel who will be directly involved in carrying out the process. These roles may overlap considerably but it is essential that all roles are adequately filled.

The *managing group* needs to insure that the project is adequately resourced and has the necessary profile within the company. The *supporting group* supplies the "expertise" in the process of strategy formulation: moving the process through the various stages, insuring that the process is adequately recorded, guiding and progressing the actions between meetings. In many cases the supporting group is actually one person, often called a facilitator. Such a person needs to be able to work closely with top management and will need to have both the personality and the technical competence to interact effectively. This is often a difficult role to fill. The issues surrounding "facilitators" are considered in detail by Rhodes (1991).

The *operating group* comprises the people who are doing the bulk of the work: collecting and analyzing the data; assessing the requirements of the business; considering alternative policies, etc. The composition of the operating group may change during the process, but should always remain multifunctional so that the benefits outlined in the section on participation can be realized.

The time scale should be discussed and agreed at the outset of the exercise. If this is not done there is grave danger of the project never reaching conclusions; there will always be more data that need to be obtained or different options that need to be explored. "Paralysis of analysis" can occur, and rather than arriving at a new strategy, the process stagnates, people become disillusioned, and the whole exercise loses credibility.

*Point of entry.* It is necessary to provide a mechanism for introducing the strategy formulation process into an organization. There needs to be a clear view of what the process involves and what type of results will be obtained. There needs to be the full agreement of the management of the company about proceeding with the exercise. This goes beyond simply insuring that everyone "knows what is going on." There needs to be some way of demonstrating to the company the necessity of proceeding with the full process. The process needs to be "sold" to the personnel who are required to be intimately involved in it.

As well as demonstrating need, the "point of entry" feature of the methodology needs to establish a common understanding within the company of what manufacturing strategy is, and of what the company might expect the outcome of the strategy process to be. It is important that management expectations are brought out into the open and discussed. These expectations will cover both the effort required (cost) and the benefits likely to be achieved. Managers are very accustomed to thinking in terms of cost/benefit analysis, and enabling them to put a strategy formulation project into this framework is beneficial. It must be recognized that the main aim of the "point of entry" stage is to obtain the agreement of the managers to committed involvement in the project. If this is not done, the process is likely to have very limited success or to have drawn out time scales. This can be traced back to poor commitment of the key players.

A comprehensive strategy formulation process should cover all 4Ps: procedure, partici pation, project management, and point of entry.

See also *content of operations strategy; manufacturing strategy; operations objectives; operations role; operations strategy; structural and infrastructural decisions*

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## manufacturing systems engineering

*Michael Gregory*

Manufacturing systems engineering (MSE) is a multidisciplinary development from the core principles of production/industrial engineering. It developed in the late 1980s (in part as a response to the contemporary resurgence of Japanese industrial performance) to address the perceived need for a broader view of the production engineering function (i.e., big "M" manufacturing rather than small "m" manufacturing). In this respect, manufacturing systems engineers should have the knowledge and skills necessary to design, control, program, and monitor both single machines and interconnected systems of machines. In addition, they should have an understanding of (soft) systems approaches to the design and operation of total manufacturing systems, so that they can incorporate advanced manufacturing techniques into manufacturing systems which support the wider objectives of the business.

See also *implementing process technology; industrial engineering; operations activities; operations management*

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## master production schedule

*Peter Burcher*

The master production schedule (MPS) is a management commitment to produce certain volumes of finished products in particular time periods in the future. The MPS "drives" MATERIAL REQUIREMENTS PLANNING (MRP). Depending on the market environment, an MPS is created for each finished product using either known customer orders, sales forecasts, or a combination of both. The MPS must also take account of the longer term production plan, any finished product stock or overdue orders, and management policies and goals. It should be realistic and achievable and hence checked against the manufacturing capacity of the key resources of the business (*see* CLOSED LOOP MRP).

The length of the planning horizon for the MPS is determined by calculating the longest cumulative lead time for the finished product and possibly adding a period of time to give the purchasing department visibility over future requirements so that it is able to take advantage of bulk purchasing discounts. Since the further ahead a forecast is made, the less accurate it is likely to be, it would be unrealistic to allow no changes to the MPS, particularly as forecasts are revised and orders are taken that consume the forecast. There are, however, increasing difficulties in making changes to the MPS the nearer the beginning or "front end" of the schedule is approached.

One method of controlling the changes to the MPS is to split the planning horizon into time zones, each of which has different constraints on the type of change that can be made. Essentially, that period of the schedule which represents finished products that are currently being assembled is usually only changed in emergency situations, since parts and subassemblies will have already been manufactured to the original schedule. This is often referred to as the "frozen zone." In that part of the planning horizon which represents parts currently being manufactured, it may be possible to alter the sequence of the finished products already scheduled, bearing in mind material and capacity availabilities. In the period which represents orders for materials that have been placed on suppliers, it may be feasible to alter the quantities of finished products on the MPS if it is possible to make the consequent alterations of material quantities on the open orders with suppliers. In the last section of the planning horizon, or "back end" of the schedule, which represents forward information for the purchasing department, it is usually possible to make alterations to both the sequence and volume of finished products scheduled, presuming, of course, that checks have first been made with the purchasing department regarding any major bulk material purchases that may have been made on the basis of the original information.

Apart from the sales of finished products, a company might also be concerned with the supply of spares in the form of components or subassemblies. These independent demands can be incorporated into an MRP system by inputting them into the MPS, thus insuring that they are added to the generated dependent demands for the items in the relevant time periods. The time periods used in the master schedule will be a result of the degree of control required in the overall production planning and control system, and for most companies it is accepted that time periods in excess of one week do not give sufficient control for the setting of priorities for manufactured components and their subsequent progressing.

Some companies have tackled the problem of the choice of time period or time "bucket" by adopting variable length periods across the planning horizon, which gives the possibility of greater control of the final assembly operations and less detailed control for the bulk purchasing of materials. Many companies are now using daily periods or so called "bucketless" systems where MPS quantities are associated with specific calendar dates using an internal manufacturing calendar.

In some market environments it may be particularly difficult or impossible to forecast every possible saleable finished product because of the combinations of options and extras that might be offered. In such cases it is not usually the finished product that is master scheduled but items at a level below the saleable product. This is achieved by utilizing planning bills of material (*see* BILL OF MATERIALS).

See also *capacity management; JIT and MRP/ERP; manufacturing resources planning; planning and control in operations*

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## material requirements planning

*Peter Burcher*

Material requirements planning (MRP) is a computer based set of planning techniques which looks at a future requirement for a finished product in terms of a MASTER PRODUCTION SCHEDULE and uses this, together with the BILL OF MATERIALS, inventory status data, and lead time information, to generate the requirements for all the subassemblies, components, and raw materials that go to make up a finished product. It suggests the release of replenishment orders for material and, since it is time phased, it makes recommendations to reschedule open orders when due dates and need dates are out of phase. In essence, MRP has been designed for a dependent demand environment with the objective of providing the right parts at the right times. MRP is also abbreviated to MRPI to distinguish it from the later development, MANUFACTURING RESOURCES PLANNING, which is abbreviated to MRPII.

The first computer programs that attempted to carry out material requirements planning calculations were produced in the late 1950s and early 1960s in the US, at a time when business computing was in its infancy. Early pioneers were Oliver Wight and Joe Orlicky, whom many authorities regard as the fathers of modern MRP. During the 1970s, the American Production and Inventory Control Society (APICS) undertook its MRP crusade, which tried to persuade US manufacturing companies that MRP was the way to plan and control materials. During the same decade, many MRP software packages were produced and sold, mostly based on the early programs that had been developed inside manufacturing corporations. Very quickly it became apparent that other resources in businesses needed planning as well as materials, and MRP evolved into CLOSED LOOP MRP and, eventually, with the linking to the other main business planning and control functions, into MRPII systems. MRP still forms the central module of the majority of commercially available production control software packages and has been referred to as the "engine" of such systems.

MRP is concerned with the manufacture of multicomponent assemblies and relies on the fact that the demands for all subassemblies, components, and raw materials are dependent upon the demand for the finished product itself. They are said to have dependent demands. There may also be some items that have independent demands, i.e., the demand for them does not depend on the demand for any other item. Notably, the finished product itself usually has an independent demand in that it depends solely on the customer purchasing the product. Components and subassemblies may also have independent demands in the form of spare parts sales requirements. In a purely independent demand environment, items could be satisfactorily controlled using classic inventory approaches such as continuous and periodic review inventory systems (*see* INVENTORY CONTROL SYSTEMS), but in a predominantly dependent demand situation, these independent demands would be the inputs to the MPS in terms of forecasts and orders that would then be processed by the MRP system.

For dependent demand items, MRP offers considerable advantages over classic inventory approaches by trying to insure that all the parts for the assembly of the product are available at the right time. In doing so, it can reduce overall stockholding costs while improving the service that the stock is providing.

The MRP calculation process involves exploding the MPS on a level by level basis through the bills of material. At each level the gross requirements for the items are first calculated, then the effect of any projected stock and open orders is taken account of to produce the net requirements, and finally, using the lead time, the net requirements are offset in time to produce the suggested or planned orders (*see* NETTING PROCESS IN MRP). The planned orders may need to be batched together to take account of physical material handling or process constraints or the costs associated with ordering or setting up processes (*see* LOT SIZING IN MRP). Also, safety factors may need to be built into the calculation process to allow for problems in supply, unreliability of processes, or short term changes in demand (*see* SAFETY STOCKS IN MRP).

The MPS needs to be as realistic and achievable as possible and, to this end, it needs to have been checked out against the capacity of the key processes in the business. The bill of materials needs to be accurate for each product, an objective that is easier to achieve in the standard product, repetitive production type of industry than in the custom built environment. Inventory records also need to be accurate, which implies good procedures, regular stock checking, and possibly the use of online stock recording systems (*see* INVENTORY ACCURACY).

MRP can be operated in one of two modes. The first is referred to as regenerative and involves the complete recalculation of all the planned orders for every item on the database for every time period into the future that has been specified. This often takes place in organizations at the end of a week or over a weekend and is thus relatively inflexible in a fast moving business environment. To overcome this infrequent updating scenario, most MRP systems have been adjusted to allow for the recalculation and rescheduling of requirements and orders based upon determining the effect on only those items that have been affected by a change. This mode of operation is referred to as net change MRP and is usually run, as requested, during the working day or, at the minimum, at the end of a shift. In a manufacturing resource planning system, MRP provides the input to various capacity planning and shop floor scheduling systems.

See also *just in time; JIT and MRP/ERP; optimized production technology; scheduling*

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## materials management

*Christine Harland*

Materials management is primarily concerned with manufacturing and production related industries and as a concept emerged in the 1950s. It is the term used to describe the grouping of management functions involved in an organization's internal material flows, from PURCHASING and transportation of materials to production planning, warehousing, shipping, and distribution of the finished product.

There are many definitions of materials management. Lee and Dobler (1977) identified that there was little agreement, at that time, on what functions were involved in materials management, LOGISTICS, and PHYSICAL DISTRIBUTION MANAGEMENT. They define materials management as "an integrated management approach to planning, acquisition, conversion, flow and distribution of production materials from the raw materials state to the finished product state." Implicitly, their definition refers to finished products within one firm rather than the flow of materials through the entire supply chain down to the ultimate consumer. More recently, some authorities have defined materials management as the cost and control of materials, incorporating all functions involved in obtaining and bringing materials into the plant; this appears to exclude movement through the plant and from the plant. However, others define materials management as including purchasing, inbound transport, storage, materials handling, inventory control, and production scheduling.

The definition of materials management appears now to be covered by the phrase SUPPLY CHAIN MANAGEMENT.

Underlying all the definitions is that materials management is a cross functional, integrative approach to managing materials and information associated with materials. Cross functional management of the materials flow from the supply end of the business to the demand end of the business is intended to yield the following benefits:

- *Increased speed of material flow*, which results in reduced lead time. This enables shorter lead times to be quoted to customers which, in speed oriented businesses, can provide the business with a competitive advantage (*see* TIME BASED PERFORMANCE).
- *Greater flexibility and ability to respond to change*: Integrating the materials flow allows the organization to respond to customer volume changes or range changes as examples.

- *Reduced cost*: Managing materials through the organization rather than in functional departments allows business wide visibility of inventories, allowing inventory reduction (*see* INVENTORY RELATED COSTS).
- *Greater dependability*: The integrated pro cesses under materials management com pared to separated functional processes can make material and order tracking easier in the organization, insuring greater depend ability (*see* DELIVERY DEPENDABILITY).
- *Improved quality*: In an organization that in tegrates the materials flow processes, quality problems are visible and made more visible to all parts of the materials flow. This also means that there is less waste in the organiza tion arising from poor quality (*see* QUALITY MANAGEMENT SYSTEMS).

See also *business process redesign; flexibility; qual ity*

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**method study**

*John Heap*

Method study is the process of subjecting work activity to systematic, critical scrutiny in order to make it more effective and/or more efficient. It was originally designed for the analysis and im provement of repetitive manual work, but it can be used for all types of activity at all levels of an organization. The process is often seen as linear, described by the following main steps:

- select (the work to be studied);
- record (all relevant information about that work);
- examine (the recorded information);
- develop (an improved way of doing things);
- install (the new method as standard prac tice);
- maintain (the new standard proactive).

Although this linear representation shows the underlying simplicity of method study, in prac tice the process is much more one of iteration around the above steps with each dominating at a different stage of the investigation. The cyclic process often starts with a quick, rough pass in which preliminary data are collected and exam ined, before subsequent passes provide and handle more comprehensive and more detailed data to obtain and analyze a more complete picture.

Work is selected for method study on the basis of its being an identified problem area or an identified opportunity (resulting from a system atic review of available data, normal monitoring or control processes, high levels of dissatisfac tion and complaint, or as part of a management derived change in policy, practice, technology, or LOCATION), and usually because it meets certain conditions of urgency and/or priority.

Before any method study investigation is begun, it is necessary to establish clear terms of reference that define the aims, scale, scope, and constraints of the investigation. This should also include an identification of who "owns" the problem or situation and ways in which such "ownership" is shared. This may lead to a debate on the aims of the project, on the reporting mechanisms and frequencies, and on the measures of success. This process is some times introduced as a separate and distinct phase of method study, as the "define" stage. It leads to a plan for the investigation which identifies appropriate techniques, personnel, and time scales.

The recording stage of method study is to provide sufficient data (in terms of both quality and quantity) to act as the basis of evaluation and examination. A wide range of techniques is avail able for recording; the choice depends on the nature of the investigation and the work being studied, and on the level of detail required. Many of the techniques are simple charts (such as process charts) and diagrams, but these may be supplemented by photographic and video recording, and by computer based techniques. Especially with "hard" (clearly defined) prob lems, method study often involves the construc tion and analysis of models, from simple charts and diagrams used to record and represent the situation to full, computerized simulations (*see* SIMULATION MODELING). Manipulation of and experimentation on the models lead to ideas for development. The recorded data are subjected to examination and analysis; formal ized versions are critical examination and systems analysis. The aim is to identify, often through a structured, questioning process, those points of the overall system of work that require improvement, and where such improvements may be made. The examination stage merges into the development stage of the investigation as more thorough analysis leads automatically to identified areas of change. The aim here is to identify possible actions for improvement and to subject these to evaluation in order to develop a preferred solution. Sometimes, it is necessary to identify short term and long term solutions so that improvements can be made (relatively) im mediately, while longer term changes are imple mented and come to fruition.

At this stage it is often necessary to present interim results (which might include a number of options that are only partially appraised) to the project sponsor. Thus, presentation and communication techniques are an important part of the method study "toolbag." The spon sor may at this stage make comments or requests that lead to further data collection and examin ation as part of the iterative process. Eventually, the process will lead to an identified and agreed solution which has to be implemented.

A method study can only be considered a success when the situation changes to solve the identified problem or take advantage of the iden tified opportunity, in such a way as to meet the aims of the project identified in the original terms of reference. The installation phase may be a major project in itself since it may involve changes in location, technology, equipment, fix tures, fittings, and tools in addition to or as part of system and procedural change. It may involve significant testing or prototyping of the pro posed method, and will almost certainly involve consultation with and training of the personnel involved. For larger projects involving major change, it may require phased implementation or parallel running of old and new systems. The aim is to balance the speed of the change with the reliability and the security of the system, recog nizing that both these have a bearing on the cost of the change. However, the most important part of making the change is often identifying and dealing with any resistance to change by person nel. It is important to fully prepare and support people through the period of change if they are to make the new method work.

After the new method has been operating for some time, there should be a check to insure that the planned changes have been adopted and maintained. Working methods can be subject to a process of "drift," by which they move away from the previously defined, standard working practices. Although such drift may be beneficial to an organization (where it improves on the method), it may also be responsible for unsafe working practices, poor quality production, or suboptimization of production – where pro cesses at different stages of an overall cycle become unbalanced. The process of monitoring and review may be a part of a formal methods audit or systematic review, or part of the remit of supervisors.

One criticism of method study is that it is inappropriate for "soft" problems, which are vague and less easily understood, cannot be rep resented by simple models, and often involve high "people content." Alternative methodolo gies (such as soft systems methodology) have been developed to cope more effectively with such circumstances, although these may be regarded simply as application of the method study procedure with a different emphasis.

See also *division of labor; empowerment; group working; job design; job enlargement; job enrich ment; job rotation; multiple activity charts; tele working; work measurement; work organization; work study*

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## modular bill

*Pamela Danese*

A modular bill is a planning bill that groups subassemblies and parts based on whether they are unique to a specific product option or common to all product configurations (Oden, Langenwalter, and Lucier, 1993). Thus the generation of the modular bills implies the identification of the product options and the grouping of the product components related to each individual product option (Orlicky, 1975). Moreover, the components common to all product configurations are grouped in a "common item" modular bill. As an example, suppose that a tractor can be sold in four different end product configurations (P1, P2, P3, P4). The customer can choose between two options: the type of motor (gasoline or diesel) and the power (50 kW or 70 kW). Each bill of material (*see* BILL OF MATERIALS) includes components that can be grouped by analyzing if they are always included in the products – such as the components "A" and "F" – or only when they contain a particular option. For example, the component "K" is included only when the tractor has a diesel engine. When all components have been grouped, it is possible to associate a code with each group of components. The resultant modular bills can then be used to build the SUPER BILL of the pseudo product "tractor."

See also *add/delete bill of materials; family bill; kit bill*

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## multiple activity charts

*John Heap*

Multiple activity charts are used to show the interrelationships of individuals in teams of workers, or the relationships between workers and equipment, usually during the record stage of METHOD STUDY. The activities of each subject (whether worker or equipment) are recorded, normally as blocks in columnar form, against a common time scale. It is not usual, or necessary, to include a high level of detail, but it is necessary to distinguish between components of work where subjects are working in an independent way (such as a worker carrying out a manual task while a machine carries out an automatic process) or in an interconnected way (such as a worker setting up or operating a machine). The resulting chart clearly shows both interdependence and interference between subjects, and their effects in terms of creating delays and unoccupied time periods. They serve as useful devices to assist in the redistribution and balancing of workloads.

See also *work study*

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# N

### netting process in MRP

*Peter Burcher*

The MRP netting process is the way MATERIAL REQUIREMENTS PLANNING (MRP) carries out calculations on a level by level basis down through a BILL OF MATERIALS which converts the MASTER PRODUCTION SCHEDULE of finished products into suggested or planned orders for all the subassemblies, components, and raw materials. At each level of assembly breakdown, MRP undertakes three steps in its calculations before continuing to the next lower level.

1 It generates gross requirements for the item by "exploding" the "planned order" quantities of the next higher level assembly, by reference to the bill of material structure file. For example, for a finished product A that requires six components *X*, a "planned order" of 200 As in week 15 would be exploded to give gross requirements of 1,200 *X*s in week 15.

2 The gross requirements are amended by the amount of inventory of that item that is expected to be available in each week, i.e., on hand from previous week plus scheduled receipts. This information is obtained from the inventory status file and the amended requirements are called the net requirements. For example, if in week 15 a total of 800 *X*s are expected to be available, the gross requirement of 1,200 is amended to give a net requirement of 400 *X*s in week 15.

3 The net requirements are then offset by the relevant lead time for the item to give planned orders for initiating the manufacture or purchase of the item. For example, if the lead time for the *X*s is 4 weeks, the net requirements of 400 *X*s in week 15 are offset as in figure 1.

To summarize, in its simplest form, MRP would calculate the requirements and planned orders for *X*s for each period of the planning horizon as in figure 2. This calculation assumes that the only use of *X* is in the assembly of A. If this were not the case, and if its usage were common to other products assembled by the organization, then the gross requirements for *X* would have been the aggregated requirements generated from the planned orders of all the assemblies using *X*. This simplified approach to the calculation of requirements has, so far, assumed that the net requirements would be translated directly into planned orders, resulting in manufacturing component schedules and purchasing schedules that do not take any account of the cost of machine setups or the cost of ordering. It may therefore be necessary to modify the net requirements by the application of batching rules or ordering policies (*see* LOT SIZING IN MRP). Similarly, no account has been taken of the need for any unplanned occurrences or short term changes in supply or demand. In such cases it may be necessary to incorporate safety factors into the MRP calculations (*see* SAFETY STOCKS IN MRP).

See also *closed loop MRP; manufacturing resources planning*

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Part no. A

| Week no. | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|
| Master schedule | 400 | 300 | 200 | 200 | 300 | 200 | 400 |

Part no. $X$ (BOM = 6 per item $A$) Lead time = 4 weeks

| Week no. | | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| Gross requirements | | 2400 | 1800 | 1200 | 1200 | 1800 | 1200 | 2400 |
| Scheduled receipts | | | 6000 | | | | | |
| Projected stock | 3200 | 800 | 5000 | 3800 | 2600 | 800 | 0 | 0 |
| Net requirements | | | | | | | 400 | 2400 |
| Planned orders | | | 400 | 2400 | | | | |

**Figure 1** An example of offsetting

| Week no. | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|
| Net Requirements | | | | | 400 | |
| Planned Orders | 400 | | | | | |

**Figure 2** An example of calculating requirements

## network coordination mechanisms

*Pietro Romano*

Network coordination mechanisms consist of (1) the informational structure defining who obtains what information from the environment, and how that information is processed and then distributed among different members partici pating in the mechanism itself, and (2) the deci sion making process helping to select the appropriate action that needs to be performed from the set of alternative solutions (Malone, 1987). Grandori and Soda (1995) reviewed the vast literature on inter firm networks and iden tified a list of mechanisms employed to sustain inter firm cooperation: communication, deci sion, and negotiation mechanisms, social coord ination and control, integration and linking pin role and units, common staff, hierarchy and authority relations, planning and control systems, incentive systems, selection systems, information systems, public support, and infra structure.

See also *bow tie and diamond perspectives; out sourcing; supply chain coordination; supply chain integration; supply chain management; supply chain risk pooling*

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## network techniques

*Ralph Levene*

Project network techniques are designed to de termine the sequence of carrying out the activ ities and thus their scheduling. In project management the scope of work is best deter mined using a structured approach such as cre ating a work breakdown structure (*see* WORK BREAKDOWN STRUCTURES). This provides a starting point to develop an effective plan of work. The techniques are known by a number of names, sometimes used incorrectly: network analysis, critical path method (CPM), and PERT (program evaluation review technique) are all terms used to describe the process by which the constituent activities of a project are assembled into a model and then analyzed by time and (potentially) resource. The model usu ally takes the form of a diagram that represents the logical relationship between activities and thus the way in which the project will be carried out.

The diagram (plan) is sometimes confused with the schedule, which is derived from the plan by analysis of the timings associated with the activities. The schedule is often shown dia grammatically as a time scaled chart – a bar chart or GANTT CHART. A schedule can also be rep resented as a list of activities with associated start and finish dates (or times). Milestones can also be identified within a plan and, as events, will only have a single date associated with them.

The essential steps in producing an analyzed plan are:

1 determine all the activities required to com plete the project;
2 produce a diagram that models their logical sequence;
3 assign durations to each activity;
4 calculate the total duration of the project and the timings of each activity (see below).

The longest path through the project network is the minimum project duration and its "critical path." Further scheduling taking into account resource needs and limitations can be carried out.

An acceptable plan may often be the result of several cycles of the steps shown above. The initial plan should represent the "best" way to carry out the project. Often the calculated end date does not match the business need. Alterna tive ways of executing the project can be ex plored, as can the possibility of using more resources. The final plan will represent the input and consideration of the project team and its stakeholders and should be widely communi cated.

Producing an acceptable plan is crucial to the future success of the project. Assembling the activities of the project and their sequence is often done together at a planning meeting. This is frequently a consensus process involving the project team; in this way they "own" the plan, although a project planner is often respon sible, in larger projects, for its formation and maintenance.

Durations rely for their estimation on both expert opinion and historical data. Poor esti mates of durations often result from time pres sures and lack of care during the estimating process.

The subsequent calculations required are simple in principle and can be done by hand but can become very complex when different work patterns are involved within the network plan. Computer software is readily available to do the calculations economically and conveni ently. The calculations involved in resource scheduling are very complex and the use of a computer is essential.

When the project is under way the activities on the critical path must run to schedule at the time calculated for each of them. If an activity on the critical path is delayed, all subsequent activ ities on its path will also be delayed and the project will take longer than the minimum time, unless remedial action is taken. Activities on the other paths have spare time, known as "slack" or "float," and these can be scheduled to make best use of the available resources. The project plan is updated regularly throughout the project with activity progress and reanalyzed to produce a revised schedule.

### Network Diagrams

The network represents the logical sequence of activities. Two diagrammatic standards exist, known as "arrow" (or "activity on arrow," AOA) and "precedence" (or "activity on node" AON) diagramming methods. Both achieve the same purpose in modeling the project and are both widely used throughout the world. Over the last 25 years the "precedence" method has become the most commonly used form and is described below. Proponents of either method frequently express a strong preference, but in all but a few instances the results are identical. Arrow diagrams handle milestones more easily, whilst the more complex inter activity relation ships are modeled better in the precedence form. Details of the arrow method are extensively de scribed in the literature.

### Precedence Diagrams

The diagram is drawn conventionally from left to right, i.e., the start will be at the left hand side of the diagram.

- *Activities*: Each individual activity is repre sented conventionally as a rectangle and is also referred to as a node.
- *Constraints*: Relationships between activi ties are known as constraints and are shown by an arrow drawn between activities indi cating preceding and succeeding activities.
- *Milestone activities*: Nodes can also be used to show important points in the plan, e.g., the START and END, although no work takes place and no time is consumed. They are often drawn using a different shape as a means of easy identification.

### The Diagram: An Example

The following activities need to be completed for a kitchen refurbishment project. Unique start and end nodes are included as good practice (see figure 1).

A upgrade and install services (water and elec tricity);
B order and deliver new kitchen units (frames and doors);
C install appliances (cooker, refrigerator etc.);
D fit new units (frames);
E fit worktops;
F fit doors to units;
G tile walls;
H lay flooring.

It is important, when creating the logical se quence, that any resource limitations are ignored; only the logic should be considered. Resource needs and availability are taken into account when scheduling the activities as part of the subsequent analyses.

Delays between activities can be imposed de liberately to stagger one activity in relation to another activity, e.g., allowing paint to dry. This is best done by assigning a duration to the constraint between activities, although the reason for the delay should be made clear in the schedule.

*Other constraints.* Although most relationships will be between the completion of one activity and the start of a succeeding one (finish to start, FS), it is sometimes necessary to use other rela tionships. In the following examples, A is the preceding activity and B the succeeding activity:

- Start to start (SS) constraints: as soon as A can start, so can B.
- Finish to finish (FF) constraints: B cannot finish until A has finished.
- Start to finish (SF) constraints: B cannot finish until A has started.

Durations can also be associated with these con straints, e.g., to show that activity B starts 2 days after A starts, there would be an SS constraint

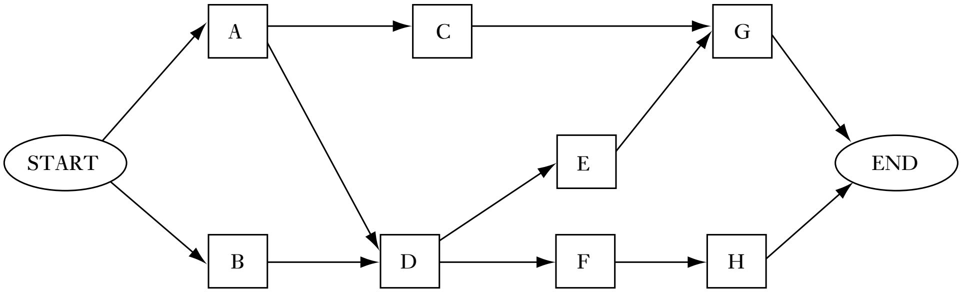


**Figure 1** An example of a precedence diagram

between A and B with a duration of 2 days. It is common practice to place the abbreviation of the relationship type above the constraint if it is SS, FF, or SF.

*Activity identity.* Each node should have a unique number or code for reference and easy location in a large project network. It is conven tional to number progressively from left to right and in practice codes often are designed to in corporate other information such as a depart ment code or even a grid system.

*Good practice in drawing network diagrams.* The first diagram is often untidy and this draft is frequently redrawn many times before publica tion. There is frequent use of removable sticky pieces of paper to accelerate the assembly of the plan. It is sometimes appropriate to plan the project in outline form and increase the level of detail as it becomes available through the pro ject. Most project management software pack ages provide graphic facilities for drawing the network, making it easier to amend and change.

*Calculation of project duration and time analy sis.* The calculation process requires the dur ations of all activities; it is carried out in two phases, the forward and backward passes. In the forward pass, the early start and finish dates (or times) are calculated for each activity. In the backward pass, the latest dates are calculated. In most cases the early and late dates will be the same for critical activities unless target dates have been imposed on the network. The spare time or "float" (or "slack") available to each activity is the difference between its early and the late dates. The critical path has zero float, so that no activity on the critical path can be delayed without it affecting the project. Where target dates are imposed on the project, the critical path will be that with minimum float.

*The effect of resources.* Insufficient resources will obviously delay the project. The extent of any delay will depend on the shortfall between re sources needed and those available. The project manager is interested not only in the following extremes but trade off positions in between:

1 How long will the project take if there are not enough resources?
2 What resources are needed to complete the project in the minimum time?

The resource needs for each activity are deter mined, as is the overall level of availability for each resource through the project duration. The resource scheduling process then takes into ac count a number of factors including activity float, criticality, and analyzed times in order to produce a new schedule. This is ideally carried out as a computerized process.

Sophisticated project management software systems allow the use of priority rules to sched ule activities and allocate resources. Some graphics based packages also allow manual manipulation of activities to show the effect of placement of activities on the resource loads.

The schedule will be changed by the effect of limited resources; this resource limited plan can now form the basis for the rest of the project. It is often frozen as the project baseline plan (or original plan). Progress will be measured against the baseline. Each activity progress can be meas ured as either the time remaining at the status date or as its percentage time complete. The statused plan is rescheduled with the data pro vided and either the plan is updated as needed or recovery plans are formulated.

In summary, the project can be represented by a logic diagram showing the interrelationship between activities. The assignment of durations and resources to the activities is then used to calculate a schedule that can be realistically achieved. This can then be used as a basis for monitoring as the project proceeds.

See also *critical chain; project control; project management; scheduling*

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## new product development process

*Michael Lewis*

The new product development (NPD) process has been the focus of continued practitioner and academic interest for nearly four decades (e.g., Schon, 1963; Kotler, 1997). Over this period a number of reviews have summarized the key success and failure variables identified in various empirical studies (including Johne and Snelson, 1988; Karakaya and Kobu, 1994; Hart, 1996). The overall significance of the NPD process has been acknowledged in the strategy, marketing, operations, and technology/innov ation literatures and this has led to many studies being conducted at different times, in different industries, and using different methodologies. As a result of this, many different success vari ables have been identified. For example, in a review of the NPD and research and develop ment literatures, Balachandra and Friar (1997) identified at least 72 success factors in a total of 19 studies, suggesting that different contexts have a major influence. It is possible to classify them according to a classic operations manage ment (OM) TRANSFORMATION MODEL.

### Inputs

Those factors classified as inputs or "starting conditions" in determining success are often "firm specific" in nature and this introduces a number of problems with generalization. For example, in analyzing Hewlett Packard's NPD process for measuring equipment, its resource based advantage (experienced engineers, PRO JECT MANAGEMENT skills, etc.) is clear but the validity and utility of positing "designer skills and experiences" as a generic NPD success factor is less obvious. Advocates of the re source/competence based model of competitive advantage (*see* COMPETENCE) argue that be cause organizational learning is a process of trial, feedback, and evaluation (*see* HIGH IN VOLVEMENT INNOVATION), the greatest chance of NPD success occurs close to an organ ization's current competence base. Therefore new product concepts will exhibit various degrees of FIT against the existing competence base of the firm. Developing core products is one tangible way of moving toward a model for as sessing and thereby increasing product feasibil ity. Sony's Walkman range, for example, was built around an evolving core platform that allowed it to introduce 160 different models in just ten years. There is also a tendency to view product development as an independent activity that takes place exclusively within the confines of the single firm. The dominance of the "manu facturer active" paradigm may result in research overlooking the crucial NPD role played by a firm's network of suppliers and/or customers.

### Process

Some studies have demonstrated that the appli cation of procedural NPD models is associated with better overall competitive performance and there is some validity to the suggestion that they represent an advance over previously "anarchic" development processes, simply because such models are more comprehensive and robust. The dominant academic and practical models describe a multistage linear process starting with the identification of new ideas. Indeed, the first five stages of Kotler's (1997) classic eight stage NPD model (progressing through idea generation, idea screening, concept testing, market strategy development, to business analy sis) are all about the generation and processing of intangible ideas. It is only in stage 6 that any actual physical product development occurs. Despite their popularity, it is also clear that such process frameworks are at best a contribu tory factor in, and are never by themselves suffi cient for, achieving strategic success. Indeed, such tools cannot deliver permanent competitive superiority because their formality (and avail ability) makes them easy for rivals to adopt.

### Outcomes

Given that so many studies infer positive NPD process characteristics from successful out comes, the measurement and analysis of "suc cess" needs to be critically appraised. Internal measures tend to be efficiency (cost) and effect iveness (speed and resource utilization) oriented – sometimes with little or no regard to overall financial performance (Brown and Eisenhardt, 1995) – whereas external measures are com monly derived from whole enterprise perform ance. This raises further concerns with the dominant methodology because the assessment of financial success requires an individual prod uct's exact costs and returns to be known. Multi firm performance comparisons therefore need to take into account the manner in which overheads (development personnel, equipment, marketing budget, etc.) are allocated in different com panies. Whilst it is theoretically feasible (*see* ACTIVITY BASED COSTING) to achieve such a separation, the complex nature of development activities is likely to result in at best imprecise, and at worst completely misleading information. As a specific example, general "brand" marketing will have a significant impact on NPD success and yet these costs will rarely be assigned to an individual new project.

There is also insufficient attention paid to failure. This is a particular concern because the single project "unit of analysis" dominates most NPD research and examining a single successful product does not emphasize the development trajectory (path dependency) inherent in organ izations. Any product that is ultimately success ful may have been dependent upon a whole series of previous failures.

### Context

As well as underplaying the specificity of indi vidual organizations, much of the NPD litera ture largely ignores the role of the competitive environment in defining success. Some studies (e.g., Cooper and Kleinschmidt, 1987) have con cluded that market dynamics have a less signifi cant impact on success or failure than internal organizational factors despite the abundance of evidence to suggest the contrary. For instance, the precise proportion of products that fail varies from market to market, with the literature reporting a range of failure rates from 37 percent to 80 percent. Where market considerations are included, they tend to generate broad general izations, such as finding that early entry into large, growing markets was more likely to lead to success. Recent work (Christensen, 1997) sug gests that customers have a crucial role to play in understanding how and why innovation works. In a comprehensive study of the disk drive in dustry, for instance, it is argued that established firms fail to respond to radical innovation not because they lack the requisite skills but because their customers (who have become structured to use the firms' current products) actually pre vent it.

See also *innovator's dilemma*

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## newsvendor problem

*Glenn Schmidt*

Suppose that you make a one time decision on how much inventory to stock to meet future uncertain demand (someone selling newspapers often faces such a problem, hence this is com monly known as the newsvendor model). For example, say you are a retailer deciding how many fashionable ski parkas to stock for the upcoming season. Suppose you are quite confi dent you will sell at least 100 units this season but are unsure about the 101st unit. If you understock (i.e., if you don't hold the 101st unit in inventory), then you lose out on the opportunity to make a profit on that unit should a customer for it materialize. We call this lost opportunity the cost of underage and denote it by $c_u$. If you sell the jacket for \$100 after buying it for \$70 from the manufacturer, then $c_u = \$100 - \$70 = \$30$ (sometimes other con siderations go into calculating $c_u$, such as loss of customer goodwill, but for simplicity we ignore those here).

On the other hand, if you go ahead and stock the 101st parka, there is a chance it will be left over, in which case you experience a cost of overstocking, which we call the cost of overage, $c_o$. For example, a liquidation firm may pay you \$20 for the jacket so that $c_o = \$70 - \$20 = \$50$.

Thus you are trading off a loss of \$50 if you overstock against an opportunity loss of \$30 if you understock. Since the cost of overstocking is greater, you want to avoid stocking the 101st unit unless you are pretty sure you can sell it. We will assume you know the probability you will sell it; in fact, we will assume you know the full probability distribution of demand. While the newsvendor framework can apply for any probability distribution, for purposes of this entry we will assume the demand distribution is normal and that you know its mean $\mu$ and its standard deviation $\sigma$. Let's assume the mean is $\mu = 120$ units (your best guess is that you could sell 120 units) and the standard deviation is $\sigma = 10$ units.

To determine whether you should stock the 101st unit, or for that matter the $x$th unit, where $x$ can be any number, we will perform a marginal analysis: you should stock the $x$th unit only if expected marginal profit from doing so exceeds the expected marginal loss. The profit you expect is equal to the profit you make if you sell it (recall that $c_u$ represents this amount) multiplied by the probability that you actually would sell it, while your expected loss from stocking the $x$th unit is the loss you incur if you don't sell it (recall that this is $c_o$) multiplied by the probability that you won't sell it. If we let $P_x$ denote the probability of selling the $x$th unit, then by the above logic we stock the $x$th unit if $P_x c_u = (1 - P_x)c_o$ or equivalently, after alge braic manipulation, if $P_x = c_o/(c_o - c_u)$. We call $c_o/(c_o - c_u)$ the "critical ratio," or $P_c$ for short. That is, we stock the $x$th unit if $P_x = P_c$, which in our example translates into $P_x = 50/(50 + 30) = 0.625$.

Note that we will sell the $x$th unit if the realized demand is equal to or more than $x$ (we will sell the 101st unit if demand is equal to 101, or 102, or anything higher). Thus $P_x$ is the probability that demand equals or exceeds $x$. Recall that, given a probability distribution curve, the probability that the realization will be greater than $x$ is the area under the curve to the right of $x$. Thus we find $P_x$, the probability of selling the $x$th unit, by using a normal probabil ity distribution table (sometimes called a $z$ table). To use such a table you typically first find $z$, the number of standard deviations that $x$ lies away from the mean, calculated as $z = (x - \mu)/\sigma$. For the 101st unit in our example, $z = (101 - 120)/10 = -1.9$. Using a $z$ table, we find the right hand tail area associated with a $z$ value of $-1.9$ is 0.971, meaning there is a 97.1 percent probability we will sell the 101st unit, such that $P_x = 0.971$. Since this is greater than the critical ratio $P_c = 0.625$, you should stock the 101st unit.

We could go on to ask about the 102nd unit, and so on. But to avoid checking all possible stocking levels, we can solve directly for the exact number to stock. Remember, our rule is that we stock the $x$th unit if $P_x = P_c$. Thus we want to find the biggest stocking level $x$ for which the probability of purchase $P_x$ is at least as big as the critical ratio $P_c$. That is, we want to find the $x$ that yields a right tail area of $P_c$. We find this by "working backwards," first using the $z$ table to find the $z$ that is associated with the right tail area $P_c$. In our example, for $P_c = 0.625$, we find $z = -0.32$. Then we find the $x$ that is associated with this value of $z$. Since earlier we said $z = (x - \mu)\sigma$, we can algebraically solve for $x$ and find that $x = z\sigma + \mu$. In our example, $x = (-0.32)10 + 120 = 116.8$. Since we can't stock a fraction of a unit, and since we always want the right tail area to be *greater* than $P_c$ (we want the marginal profit to *exceed* the marginal loss), we always have to round down. (Admittedly, the uncertainty inherent in describing the demand distribution and in measuring the costs of underage and overage probably overshadow this rounding subtlety.) Thus in our example, we stock 116 units.

See also *aggregate capacity management; capacity strategy; forecasting process; inventory management*

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# O

## operational anorexia

*Zoe Radnor*

Although LEAN PRODUCTION has become the dominant operations management (OM) logic, some authors highlight the potential downsides of excessive "leanness" by dramatically comparing it with the eating disorder anorexia (Stamps, 1996). In other words, if managers always rely upon cost cutting and downsizing when faced with challenging competitive circumstance, "[they] . . . become so skinny they'll be the last to get healthy again" (Neuharth, 2002). Less emotively, "operational anorexia" can be explained if one considers that because lean production is only achievable if regarded as an ongoing "journey," then inevitably some operations striving to become lean (i.e., focusing on process) may miss their optimum "leanness" and move into anorexia, becoming relatively ineffective overall. Employing another metaphor, materials can only be stretched elastically to a certain point before permanent (plastic) distortion occurs.

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## operations activities

*Nigel Slack*

Operations activities are the clusters of tasks to be completed (and decisions to be taken) which together delineate the boundaries of what constitutes operations management (OM). The concept is useful in so far as it introduces a distinction between OM activities and techniques. Techniques are the theories, models, typologies, and heuristics intended to help decision making in OM and a single technique may be used to support more than one activity. There are two main approaches to such a categorization.

### Clustering Activities around Resources

For example, operations activities can be divided into those concerning product or service related decisions (such as design, QUALITY, and reliability), plant related decisions (such as LOCATION, LAYOUT, and MAINTENANCE), process related decisions (such as INDUSTRIAL ENGINEERING and quality control), program related decisions (such as forecasting, operations planning and control, INVENTORY MANAGEMENT, PROJECT MANAGEMENT, and PURCHASING), and people activities (such as JOB DESIGN and health and safety management). A more common approach and one which is almost universally used in the operations strategy area is that which distinguishes between structural and infrastructural activities (Hayes and Wheelwright, 1984).

### Clustering Activities Chronologically

At its simplest level, this involves grouping activities into those which concern design, those which concern planning, and those which concern control. Sometimes planning and control are grouped together. Design activities would include such tasks as product or service design, layout of physical facilities, job design, and technology choice. Planning and control activities would include such tasks as capacity planning and control (*see* CAPACITY MANAGEMENT), inventory management, SCHEDULING, quality control, and plant maintenance. More recently this approach has been extended to include improvement activities to follow design and planning and control activities. A more explicit chronological approach is taken by Chase and Aquilano (1992), who classify activities under the headings of design, systems start up, steady state activities, and improvement activities. Design activities include product and service design, design for TOTAL QUALITY MANAGEMENT, capacity and location decisions, facilities layout, and job design. Start up includes project planning and control activities. Steady state decisions include aggregate capacity planning (*see* AGGREGATE CAPACITY MANAGEMENT), inventory management, scheduling, and MATERIALS MANAGEMENT. Improvement activities include managing the CONTINUOUS IMPROVEMENT process and revising OPERATIONS STRATEGY.

See also *content of operations strategy; forecasting process; life cycle effects; operations management; operations role; manufacturing strategy; planning and control in operations; service strategy; structural and infrastructural decisions*

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## operations management

*Nigel Slack*

Operations management (OM) is the managerial role (sometimes functional label) and academic discipline concerned with the way that for profit and not for profit organizations produce goods and services. As Slack, Chambers, and Johnston (2004) argue, "everything you wear, eat, sit on, read . . . every book you borrow from the library, every lecture you attend at university – all have been produced. While the people who supervised their 'production' may not always be called operations managers, that is what they really are." For example, they might be called fleet managers in a distribution company, administrative managers in a hospital, or store managers in a retail operation. The term "operations management" has emerged to suggest distinctions from the narrower but more established subject of "production management."

1. OM, even in manufacturing organizations, is seen as including more than solely its core manufacturing activities. Other activities associated with the total set of material transformation processes are also included, such as PURCHASING and distribution. Even broader definitions of OM in a manufacturing context would also include associated activities such as process engineering, design engineering, and some management accounting activities.
2. OM is used to indicate production activities in both manufacturing and non manufacturing organizations. It is this latter distinction that has also led to the concept of operations management being seen as relevant in organizational areas other than the core production or service producing "operation."

Many of the issues, methods, and techniques that apply to the core operations function also have meaning for each unit, section, group, or individual within the organization. For example, a marketing function can be viewed as an oper ations system with inputs of market information, staff, and computers, and outputs of marketing plans, advertising campaigns, and sales force organizations. Thus, all organizational functions can be viewed as operations themselves because they are there to provide goods or (more usually) services to the other parts of the organization. Each function will have its "technical" know ledge. For example, in marketing this is the expertise in designing and shaping marketing plans, in finance it is the technical knowledge of financial reporting. Each will also have an operations role of producing plans, policies, and reports and service.

In conclusion, although there is a danger that such a broad subject definition risks offering no analytical clarity, it remains important to high light two meanings of "operations": operations as a function, meaning the part of the organization that produces the goods and services for the or ganization's external customers, and operations as an activity, meaning any transformation of input resources in order to produce goods and services, either for internal or for external customers.

See also *ethics in operations management; hier archy of operations; history of operations manage ment; operations activities; operations role; operations strategy; service operations; transform ation model*

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### operations objectives

*Nigel Slack*

Operations objectives are the explicit dimen sions of performance against which an operation will attempt to satisfy market requirements: as a result they do not usually include measures such as return on investment or market share – even if they directly influence these metrics. Nor are they the same as the general role or aspirations that the operations function may have; rather, their purpose is to translate market positioning and competitive factors into an operations rele vant format. Of course, if these objectives are to have any meaning for an operation, they must relate to attributes of organizational performance that OPERATIONS ACTIVITIES can influence in some way. In other words, "reliable consumer electronics" needs to be translated into, for in stance, $x$ parts per million defective as a quality objective. Many authors have defined generic sets of performance objectives. They are referred to variously as "performance criteria," oper ations "strategic dimensions," "performance dimensions," "competitive priorities," or "stra tegic priorities." Fundamentally, although there are specific differences between authors, there is a set of commonly used categories: QUALITY, speed, dependability, FLEXIBILITY, and COST. In addition, some authors include more diffuse objectives such as "innovativeness" as part of the set of operations objectives. By this they mean the ability of the operation to intro duce novel products or services, or introduce new process technologies or methodologies into their operations. A more pragmatic way of incorporating innovativeness might be to include it as either a subset or consequence of flexibility. Other terms that have been used to describe operations objectives in clude "competitive factors," "critical success factors," "order winners," and "competitive priorities."

See also *design chain; life cycle effects; operations role; operations strategy; performance measure ment; sandcone model of improvement; service strategy*

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## operations role

*Nigel Slack*

The "role" of the operations function refers to the set of long term strategic responsibilities that are seen as being its prime concern, and from that the part it has to play in achieving competi tive success. Usually the term is used to mean the underlying rationale of the function.

The best known approach to defining oper ations role considers the organizational aims or aspirations of the operations function. Hayes and Wheelwright (1984) developed a "four stage" model that can be used to evaluate the competi tive role and contribution of the operations func tion of any type of company. The model traces the progression of the operations function from what is the largely negative role (called stage 1 operations) to its becoming a central element of competitive strategy (called stage 4 oper ations).

Stage 1, or "internal neutrality," is the poorest level of contribution by the operations function. In a stage 1 organization the operation is considered a "necessary evil." The other func tions regard the operations function as holding them back from competing effectively. Oper ations has little that is positive to contribute toward competitive strategy. It is unlikely even to have developed its resources so as to be ap propriate for the company's competitive pos ition. The best that the function can hope for is to be ignored in so far as when operations is being ignored, it is not holding the company back. The rest of the organization would not look to operations as the source of any originality or competitive drive. In effect, the operations function is aspiring only to reach the minimum acceptable standards implied by the rest of the organization. It is trying to be "internally neu tral," a position it attempts to achieve not by anything positive but by avoiding the more obvious mistakes.

Stage 2, or "external neutrality," envisages the operation breaking out of stage 1 by meeting the minimum internal performance required and comparing itself with similar companies or or ganizations in the outside market. This may not immediately result in its taking a leading pos ition in the market, but at least it is aspiring to reach that position and is measuring itself against its competitors' performance. Although not particularly creative in the way it manages its operations, it is trying to "be appropriate," by adopting BEST PRACTICE from its competitors. In taking the best ideas and norms of perform ance from the rest of its industry, it is trying to be "externally neutral."

Stage 3, or "internally supportive," oper ations have probably reached a leading position in their market. They may not be better than their competitors on every aspect of operations performance, but they are broadly up with the best. Nevertheless, good as they may be, stage 3 operations aspire to be clearly and unambigu ously the very best in the market. They try to achieve this by gaining a clear view of the com pany's competitive or strategic goals, after which they organize and develop the operations re sources to excel in the things that the company needs to compete effectively. Not only are they developing "appropriate" resources, they are also taking on the role of the "implementers" of strategy. The operation is trying to be "in ternally supportive" by providing a credible op erations strategy.

Stage 4, or "externally supportive," oper ations go further in attempting to capture the emerging sense of the growing importance of operations management. In essence, a stage 4 company is one that sees the operations function as providing an important foundation for its future competitive success. The operations function looks to the long term. It forecasts likely changes in markets and supply, and it develops operations based strategies that provide the company with the performance that will be required to compete in future market conditions. In effect, the operations function is becoming central to strategy making. Stage 4 operations are creative and proactive. They are likely to organize their resources in ways that are innovative and capable of adaptation as markets change. Essentially, they are trying to be "one step ahead" of competitors in the way that they create products and services and organize their operations, what Hayes and Wheelwright call being "externally supportive." Operations are not only developing "appropriate" resources and "implementing" competitive strategy, they are also an important long term "driver" of strategy.

The Hayes and Wheelwright four stage model may be a simplification, but two points are worth considering. First, it assesses the performance of operations by the function's *aspirations*. Second, as companies move from stage 1 to stage 4, there is a progressive shift in operations' contribution from being negative and operational through to being positive and strategic. For both reasons, the model has become widely used by both academics and practitioners.

See also *manufacturing strategy; operations activities; operations management; operations objectives; operations strategy; service strategy*

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## operations strategy

*Nigel Slack*

Operations strategy is a term that is often used to indicate one of two departures from the better known term, MANUFACTURING STRATEGY.

The first use of the term is to imply a broader approach to manufacturing strategy so that it includes the whole chain of functions that deliver products to customers and provide ongoing support to customers. Functions represented in this approach include PURCHASING, manufacturing itself, PHYSICAL DISTRIBUTION MANAGEMENT, and customer support services (*see* CUSTOMER SUPPORT OPERATIONS). In this sense manufacturing strategy is expanded to include all the SUPPLY CHAIN MANAGEMENT issues.

The second use of the term is to indicate the strategic management of the resources that create goods or services in any type of organization. Here the term is being used to include both manufacturing strategy and SERVICE STRATEGY. This latter approach is sometimes criticized for failing to reflect the differences between manufacturing and service organizations. So, for example, it is argued that the far larger overlap between "operations" and "marketing" activities in SERVICE OPERATIONS precludes a common approach to the strategic management of their operations functions.

More recently, operations strategy has been characterized as an attempt to *reconcile* the *requirements* of the market with the operations' underlying *resource capabilities* (Slack and Lewis, 2002). These two perspectives on operations strategy need not necessarily conflict, nor are they "alternative" views of how operations strategy should be formulated. Operations managers, it is held, should, and can, hold both views simultaneously. They represent two starting points for understanding the nature, scope, and rationale of operations strategy. By bringing both views together, the dilemmas inherent within an existing operations strategy may be exposed. A company may find that its intended market position is matched exactly by the capabilities of its operations resources, the strategic decisions made by its operations managers having, over time, generated precisely the right balance of performance objectives to achieve a sustainable competitive advantage in its markets. However, it may not. In fact, the picture in most organizations is often not well understood and, where it is understood, the capabilities of its operations resources are unlikely to be in perfect alignment with the requirements of its markets over the long term. The objective of operations strategy is to attempt an approximate alignment over time without undue risk to the organization, in a process that is ongoing and iterative.

This interaction between market requirements and operations resource capabilities is usually complex. Partly the complexity lies in the difficulty most organizations have in clarifying either the nature of market requirements or the characteristics of their operations resources. Partly it may be because insufficient effort is put into clarifying intended markets. Operations strategies may be formulated without the context of a well understood market and/or business strategy. However, even with a conventional statement of market strategy, the meaning of "market requirements" may be unclear for the operations function. A company may compete in many different markets which exhibit sometimes subtle, but nevertheless important, differences in their requirements. Furthermore, markets are dynamic. Customer behavior may change for reasons that become clear only after the event. Competitor reaction, likewise, can be unpredictable and sometimes irrational. Above all, it is important to understand that the links between customers, competitors, and market positioning are not always obvious. Market positioning is not an exact science and the strategic reconciliation process of operations strategy may have to take place under conditions of both uncertainty and ambiguity.

The operations resources side of the equation may be equally unclear. Businesses do not always know the value, abilities, or performance of their own resources and processes. Notwithstanding the popularity of the "core competence" concept, organizations frequently find difficulty in identifying what are, could be, or should be, their core competences. More significantly, the resources and processes within the operation are not deterministically connected, like some machine where adjustments to levers of control lead inexorably to a predictable and precise change in the behavior of the operation. The cause–effect mechanisms for most operations are, at best, only partially understood.

See also *competence; operations management*

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## optimized production technology

*Peter Burcher*

Optimized production technology (OPT) is both a philosophy (the OPT concept) and a planning and scheduling software (OPT), the name OPT being a registered trademark of the Scheduling Technology Group Ltd. The OPT philosophy and software aim to achieve the stated goal of manufacturing, which is to make money now and in the future. It does this by synchronizing manufacturing by concentrating on the capacity constraining resources of the business. The philosophy of OPT was first expounded by Dr Eliyahu Goldratt, most notably in his book *The Goal* (1984). Goldratt introduced three new measures that he claimed are needed to assist in decision making at the operational level in a manufacturing company. These are throughput, inventory, and operating expense. While these may sound familiar terms, the measures are unique to Goldratt because of his precise definitions of them.

Throughput is defined as the rate at which the company makes money through sales. Thus, for example, the sale of factored goods would be covered by the definition, as would the sale of spares. Inventory is defined as what the company has purchased with the intention of selling. In this definition, items that are normally classified as inventory, but which are not ultimately for sale, are ignored. Thus engineering spares and consumable items are excluded. Also implicit in the definition is the concept of valuing all inventory at raw material value. Finally, operating expense is defined as all the money required to turn inventory into throughput. The argument for putting together both direct and indirect expenditure under one heading is that, in practice, direct labor is fixed.

The three measures are in a form that can be used as a guide to operational decision making. It is reasonable to ask a foreman to consider whether running overtime, which will certainly increase operating expenses, will also increase throughput or merely end up as inventory. These three measures can be shown to have direct impacts on the traditional measures of business performance, namely, profit, return on investment, and cash flow. The ideal situation would therefore be to schedule a factory in such a way that throughput is increased while, simultaneously, operating expenses and inventory are reduced.

The OPT scheduling approach focuses attention on those resources that constrain capacity and hence the throughput of a plant. These are called capacity constraining resources or CCRs. This name was adopted because the term BOTTLENECKS was found to be too restrictive when applied using the definition given by Goldratt (a resource whose capacity is equal to or less than the demand placed upon it).

The CCR is seen as the heartbeat of the plant. It is, essentially, the resource (or resources) that controls the flow of materials. It is referred to as the "drum" by Goldratt, indicating it provides the drumbeat to which the total operation should work. The relationship between the CCR or the final stage after the CCR and those resources that feed them is referred to as the "rope," this being the mechanism which triggers the release of material to the first manufacturing stage in synchronization with the CCR schedule. Finally, there is a requirement to buffer the most vulnerable parts of the operation against uncertainty. These are the CCR, because production lost through the CCR is lost sales, and before final assembly. Note that one obviously cannot prevent the CCR from breaking down.

The "buffer" is to insure that the CCR is never starved of work because of breakdowns elsewhere. The inherent slack associated with all other operations acts as its own buffer. The entire scheduling concept is referred to as the drum, buffer, and rope.

The ideas of synchronization are incorporated, to a degree, in the OPT software. However, there is an important distinction in the software between scheduling and modeling. The basic premise is that the OPT scheduling rules are the correct ones for scheduling a plant; what varies between plants is manufacturing strategies, operations and product structures, resources, working practices, and quality policies. In consequence, it is possible to build a model using the OPT software that is unique to each plant and then apply the scheduling rules to that model to validate it by producing feasible schedules.

Models in the OPT system have two major components, dynamic and static data. The dynamic data include orders, inventories, and open purchase orders. The static data include the BILL OF MATERIALS, routings, and resource listings. All these data are usually to be found on the database of a MANUFACTURING RESOURCES PLANNING (MRPII) system. The OPT modeling language is flexible enough to permit quite complicated operations to be represented.

In the scheduling part of the OPT software there are three major program elements corresponding to the drum, buffer, and rope. The first uses a simulation technique to schedule the CCRs identified to it, forwards in time to finite capacity to derive delivery dates (*see* SIMULATION MODELING). It works on the basis that since these resources are CCRs, they should aim always to be fully loaded. The rope is provided by a backwards scheduler which ignores capacity and uses the forward schedule of the CCR as its MASTER PRODUCTION SCHEDULE. As such it is a pull system. The buffers are inserted using predetermined rules, in the key areas identified in the theory. The OPT scheduling software also takes account of the fact that increased throughput can only come about by better utilization of the CCR facilities, and increased batch sizes are one way to increase utilization. OPT calculates different batch sizes throughout the plant, depending on whether a work center is a CCR or not. The key to lot sizing in OPT is distinguishing between a transfer batch (that quantity that moves from operation to operation) and a process batch (the total lot size released to the shop). The basic concept is to move material as quickly as possible through non CCR work centers in small batches until it reaches the CCR. There, work is scheduled for maximum utilization of the CCR in large batches. Thereafter, work again moves at maximum speed in small batches to finished goods. What this means for lot sizing is very small transfer batches to and from the CCR, with a large process batch at the CCR (*see* LOT SIZING IN MRP).

The OPT philosophy has evolved. To more clearly separate OPT's philosophical concepts from the computer software, Goldratt and his associates have coined the term "theory of constraints" (TOC) to represent their ideology. Here the definition of a constraint has been extended beyond the factory shop floor and the goal is to break the constraints and thereafter identify the next constraint in a CONTINUOUS IMPROVEMENT program.

See also *just in time; planning and control in operations; scheduling*

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## order winners and qualifiers

*Martin Spring*

The order winners/qualifiers distinction ascribed to Hill (1993) is a widely adopted approach to distinguishing between the different competitive factors that operations may choose to emphasize. The basis of the classification is that different competitive factors can play different roles in determining the competitive contribution of the operations function.

Order winning competitive factors (simply called order winners by Hill) are held to be those on which better performance will result in more business, or an increased chance of gaining more business. Qualifying competitive factors (called qualifiers by Hill), on the other hand, are those for which performance has to be above a particular level in order for the product or service offered to be considered by the cus tomer, but do not, if improved beyond that level, appreciably affect the customer's buying deci sion. This suggests that, for factors identified as qualifiers, there is little to be gained by improv ing them beyond the ''qualifying'' level, whereas for order winners, effort expended in improving performance should continue to lead to more orders.

The distinction between order winners and qualifiers as a concept is widespread in the oper ations strategy literature. It has been taken up by many authors and is generally regarded as being both practical and conceptually useful. Similar concepts are evident in other areas of manage ment. Most notably, the distinction between motivating and hygiene factors in describing behavior can be viewed as a strong influence on the order winner/qualifier concept. The ''suc cess producer'' and ''failure preventer'' concept used in competitive strategy also represents a similar distinction.

Although widely cited, the order winner/ qualifier distinction is not without its critics. The first criticism is that order winners and qualifiers might change over time. However, Hill does emphasize that both order winners and qualifiers should be regarded as context and time dependent. It is also suggested that competitive criteria cannot be improved in isol ation from one another, but that, for example, to achieve sustained cost reduction, an operation must perform well in terms of conformance quality. Under those circumstances, it may be difficult for an operation to cease investing in what is believed to be a qualifier, because it is connected in some complex way to other factors identified as order winners. Operationalizing the order winner analysis also presents problems: Hill's approach suggests fairly detailed data col lection on orders placed by customers, which runs the risk, particularly in business to busi ness markets, of neglecting important inter organizational factors such as long term collab orative relationships.

Finally, the increased importance in the past few years of the resource based view of strategy, and its implications for operations, raises further doubts. By definition, the order winner/quali fier concept is very much a market requirements perspective; indeed, that is true of the Hill method as a whole. As such, it is argued that it takes insufficient account of the operations re source perspective, which would suggest that attempting to base long term strategy largely on transient product/market phenomena is misguided.

See also *manufacturing strategy; operations objectives; performance measurement; zone of tol erance*

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## organization of development

*David Twigg*

There are many structures under which product/service or process development can be organized. Pragmatically, the final choice of structure will also depend upon the availability of resources, the competitive environment (such as the speed of product introduction), and the age and variety of the product base. A spectrum of alternative structures can be considered, from a pure functional organization to those with a much greater emphasis on tighter PROJECT MANAGEMENT such as pure project based teams. Lying between these extremes are the various forms of matrix organization.

### Functional Organizations

This is the traditional hierarchical organization under which a project is subdivided and assigned to specialist groups operating within functional areas (such as engineering, production, marketing, and administration), and whereby authority for the development project cascades down through the organization from senior management through the ranks of middle management to the lower management levels. In this way, the project is passed sequentially (as a completed task), like a baton in a relay race from one team member to the next. The main responsibility for the project shifts from function to function as it progresses, and is coordinated by the respective functional heads. Any liaison will be conducted through the head of function.

Projects organized in this way have several advantages. First, the simple structure makes economical use of managerial tasks and control. Second, it enables the centralization (or pooling together) of available experts and resources, especially important in the innovation process where specialist technical expertise is critical, costly, and often scarce. Third, clearly defined career paths, and peer grouping, can assist the hiring and retaining of specialist staff. However, there are also clear weaknesses with this form. When a multitude of projects is being undertaken simultaneously, competition for resources can lead to conflicts over the relative priorities of individual projects. Functional speciality can lead to an over emphasis of the departmental goals rather than to achieving the goal of the project. Finally, there may be a lack of motivation or enthusiasm when commitment of personnel is spread across projects.

### Project Teams

This form consists of a project manager who is given responsibility for a development project team composed of a core group of personnel from several functional areas, assigned on a full time basis for the duration of the project, while other staff may be seconded to the team as required. This team is separated from the functional structure of the rest of the company and controlled by a manager responsible for the completion of the project. The company's functional managers need have no formal involvement in the team. The project manager has responsibility for both internal coordination and external integration, and has direct control of all personnel throughout the life of the project. In this way, responsibility is centered on one individual, who coordinates the entire process, rather than the distributing of authority inherent in the functional structure.

The advantages of this structure are the singleness of purpose and unity of command, the clear focus of a single objective, the effectiveness of informal communication, and the central authority of all the necessary resources. In particular, the development of team work, together with a single leader, enables conflict to be managed efficiently. On the downside, this structure disrupts the regular organization, since the individual project is only a temporary event (even if "temporary" means several years). Facilities are inevitably duplicated and therefore may be used inefficiently, and personnel may have problems reentering the organization after project completion, such as personnel losing their "home" in the functional structure while working away on the project.

### Matrix Organizations

Firms are unlikely to adopt either of these pure forms. Instead they usually choose a balance between the two. They may consider adopting a structure combining the characteristics of both the functional and project organization. This is matrix management, a mixed organizational form in which the functional hierarchy is overlaid by some form of lateral authority, influence, or communication. In a matrix, there are usually two chains of command, one along functional lines and the other along project lines. Three forms of matrix are commonly defined: functional matrix, balanced matrix, and project matrix.

- The *functional* (or lightweight) form of matrix maintains personnel in their functional groups, but designates a project manager with limited authority to coordinate the project across the different functional areas. The project is entirely under the control of the project manager, who coordinates, liaises, and monitors its progress. Each functional area is represented through a liaison representative who relates issues to the project manager. However, the functional managers retain responsibility and authority for the design and completion of technical requirements within their discipline (specific to elements of the project), and hence to the allocation of resources. The project manager is considered lightweight because: he has no direct influence over technical staff and has little leverage over activities outside of engineering (such as manufacturing and marketing) despite having liaison representatives; he has little status or power within the organization; the project manager role is effectively only one of coordination.
- In the *balanced matrix* form, the project and functional managers share the responsibility and authority for completing the project. They jointly direct many work flow elements and jointly approve many decisions. More specifically, project managers schedule, control, and monitor the timing and activities of the project, and integrate the contributions of the various disciplines, while functional managers assign personnel and execute their part of the project according to the plans of the project manager.
- The *project matrix* requires a stronger project manager than under the previous matrix structures. A project manager is assigned to oversee the project and has primary responsibility and authority for completing the project. Staff working on the project will be under the control of the project manager, although they are likely still to reside in their specific functions. Similarly, functional managers will assign personnel as needed, provide technical expertise, and oversee the long term career development of their own personnel. It is essential that the project manager is able to command authority over the functional heads, hence it is likely that she or he will be relatively senior, or at least equal to them. The heavyweight project manager can be characterized as follows. First, the project manager will have direct influence over the personnel working in the various functions – engineering, marketing, and manufacturing. Second, since the project manager will be of senior management level (head of function, or chief engineer of a division), she or he will wield considerable status and power within the organization. Third, the project manager plays an active role in directing and evolving the product, thus performing more than mere coordination of activities.

Amongst the criteria that can be used to assess the effectiveness of different structures, two are particularly important to product/service and process development: specialization and integration. Specialization is important because it encourages the depth of knowledge and technical understanding that are required in a concentrated form during the development process. Integration is important because both products and services are composed of smaller components or subsystems. Both these criteria need to be incorporated in the organizational structure that is built to support any development project.

See also *design for manufacture; design–manufacturing interface; product design process; project leadership; service design*

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## outsourcing

*Ronan McIvor*

Outsourcing involves the sourcing of goods and services previously sourced internally from external suppliers. It has become one of the key issues to have emerged for the supply chain strategy of many organizations. The term outsourcing can cover many areas, including the outsourcing of manufacturing as well as services. The drive for greater efficiency and cost reduction has forced many organizations to increasingly specialize in a limited number of key areas. For example, Unilever, with a portfolio of 1,600 food, household, and toiletries products, decided that in order to increase sales and profitability, it would focus on a smaller number of "power brands" – core products – that have global reach, thereby reducing costs and exploiting new distribution channels (Willman, 1999). In the past, organizations may have performed a range of activities internally based upon cultural, historical, or political reasons rather than on the basis of enhancing the needs of customers or achieving competitive advantage. However, now many organizations have begun to challenge these assumptions and are restructuring their organizations in order to reflect changes in the business environment. This has led organizations to outsource goods and services traditionally carried out in house.

Although, the term outsourcing has come into vogue in the last number of years, organizations have always made decisions on determining the boundary of the organization. However, the increasing prevalence of outsourcing has led to the concept receiving a significant amount of attention from both academia and practitioners. Outsourcing has moved on from focusing primarily on the peripheral activities of the business such as cleaning, catering, and security to encompass more critical areas of the business such as design, manufacture, marketing, distribution, and information systems. In particular, the movement of many telemarketing service activities such as after sales support and direct marketing offshore (sometimes referred to as *offshoring*) to developing economies has provoked much debate in developed economies. Many organizations have outsourced services to offshore locations in order to access service providers with much lower labor costs. For example, call centers in India with much lower labor rates can typically attract a high number of applications from well qualified and highly literate graduates. The use of offshore sources has already expanded to include information technology activities with some financial service organizations outsourcing transaction processing activities. However, many organizations have decided against outsourcing because they believe that foreign service providers cannot provide comparable levels of service to those of local service providers. Some of the potential savings in labor costs have to be weighed against the additional costs and difficulties associated with managing operations in distant locations. Also, organizations have avoided offshoring activities due to adverse publicity and the potential damage to their reputation.

The trend toward increased outsourcing has also been influenced by wide ranging reforms occurring in public sector organizations in many countries. For example, successive governments in the US and UK have pursued radical public sector reforms that have placed at their heart the use of competitive market mechanisms. Proponents of this philosophy argue that assets and activities should be transferred from the public sector to the private sector in order to improve performance and the public sector should aspire to levels of performance attained in the private sector. In a study of public sector organizations carried out in a number of countries including the US, the UK, France, Germany, Japan, and Australia, Domberger (1998) found that outsourcing had become a significant and increasing practice. Much of the force behind this trend has been the prevailing belief that best value is achieved through the use of competitive market solutions for service provision. For example, the impetus for greater application of market forces to the public sector in the US came from the publication of

*Reinventing Government*, which emphasized the benefits of competition and customer choice as a means of delivering better and more cost effective services to citizens. In the UK during the 1980s and 1990s, successive governments pursued policies that encouraged free market mechanisms in the public sector and discouraged state intervention where possible. Market mechanisms have also been prevalent in developing countries. For example, in Thailand utility industries such as electricity have been privatized, which has involved the separation of generation from transmission and distribution under a mixed system of public and private ownership (Cook, 1999).

POTENTIAL BENEFITS OF OUTSOURCING

Organizations can achieve a number of benefits with successful outsourcing:

- *Cost reduction*: Many organizations are motivated by cost considerations in adopting outsourcing strategies. In a study by Price Waterhouse Cooper (1999), it was found that most western organizations primarily employed outsourcing to save on overheads through short term cost reductions. Outsourcing enables the customer to benefit from supplier cost advantages such as economies of scale, experience, and location. Suppliers may take on investment and development costs while sharing these risks among many customers and thereby reducing supplier costs for all customers. For example, in the financial services industry many banks have outsourced high volume transaction processing functions such as electronic payments and processing of cheques to service providers with greater economies of scale in order to make the cost of each transaction much lower.
- *Performance improvement*: Suppliers can achieve much higher levels of performance in certain activities than can be achieved internally by the outsourcing organization. This performance advantage is based not only on reduced costs. Specialist suppliers can provide the outsourcing organization with a higher level of service quality.
- *Flexibility*: In the past, many organizations have attempted to control the majority of activities internally on the assumption that controlling supply sources eliminates the possibility of short run supply shortages or demand imbalances in product markets. However, such a strategy is both inflexible and inherently fraught with risks. Due to issues such as rapid changes in technology, reduced TIME TO MARKET, and increasingly sophisticated consumers, it is very difficult for organizations to control and excel at the activities that create competitive advantage.
- *Specialization*: Outsourcing can allow an organization to concentrate on areas of the business that drive competitive advantage and outsource less critical activities, enabling it to leverage the specialist skills of suppliers. Through extensive outsourcing, organizations have created networks of product and service providers specializing in their own distinct area of expertise.
- *Access to innovation*: In many supply markets significant opportunities exist to leverage the capabilities of suppliers into the product and services of the customer organization. Rather than attempt to replicate the capabilities of a supplier network, it is much more prudent to use outsourcing to fully exploit the suppliers' investments, innovations, and specialist capabilities. For example, suppliers provide virtually all Dell's component design and innovation, software, and production for its computers. It invests in areas where it perceives an opportunity for unique added value and avoids large inventory and development risks incurred by many of its competitors (Quinn, 1999).

POTENTIAL RISKS OF OUTSOURCING

Organizations can incur considerable risks if they fail to effectively evaluate and manage the outsourcing process.

- *Cost increases*: When organizations outsource for cost reduction, there is normally an early anticipation of cash benefits and long term cost savings. However, many organizations fail to account for future costs and in particular that of managing the outsourcing process (Barthelemy, 2003). For example, there is a tendency to underestimate the management resources and time that have to be

invested in outsourcing. Some organizations fail to realize that resources have to be invested in managing the relationship with the supplier, which is particularly important in the case of the outsourcing of critical business activities.
- *Supply market risk*: Organizations can en counter significant risks when they use the supply market for activities that they have controlled in the past. Overdependency on a particular supplier can lead to significant risks in terms of cost, quality, and supplier failure. For example, suppliers may fail to achieve the necessary quality standards demanded by the outsourcing organization.
- *Loss of skills*: Outsourcing can lead to the loss of critical skills and the potential for innov ation in the future. In the long term an organ ization needs to maintain innovative capacity in a number of key activities in order to exploit new opportunities in its respective markets. If an organization has outsourced a number of these critical activities, its ability to innovate may be severely diminished.
- *Organizational change*: Outsourcing has sig nificant social implications for an organiza tion. Outsourcing involves redrawing the traditional boundary between the organiza tion and its supply base. For example, out sourcing can lead to the redeployment of staff within the customer organization or the transfer of staff to the supplier organiza tion. The demands associated with outsour cing transcend organizational boundaries, and therefore the approach to managing the change process must insure that comple mentary activities and behaviors are ex hibited within and between organizations. For example, a new focus on quality and customer relationships necessitates changes in policies, cultural values, work procedures and processes, relationship between depart ments, and interactions between buyers and suppliers.

A number of key aspects of outsourcing evalu ation and management are described below (McIvor, 2000).

### Critical Activity Definition

Organizations must identify their critical and non critical activities. A critical activity is central to the organization successfully serving the needs of potential customers in each market. The activity is perceived by the customers as adding value and therefore being a major source of competitive advantage. Distinguishing be tween critical and non critical activities is a com plex task, and care must be taken to insure the long term strategic considerations and true benefits are assessed. This process should be carried out by top management along with inputs from teams at lower levels in the organiza tion. Each team should encompass a broad section of members – functionally, divisionally, and hierarchically. Non critical activities for which the organization has neither a critical strategic need nor special capabilities should be outsourced. By adopting this approach, organizations can build their strategies around activities that are a source of competitive ad vantage and outsource as much of the rest as possible.

### Capability Analysis

Each critical activity must be benchmarked against the capabilities of all potential external providers (both suppliers and competitors) of that activity (*see* BENCHMARKING). This will enable the identification of the relative perform ance for each activity along a number of selected measures. Resources should be focused on the activities where preeminence can be achieved and unique customer perceived value can be delivered. A key strategic issue in the outsour cing decision is whether an organization can achieve a sustainable competitive advantage by performing a critical activity internally on an ongoing basis. Many organizations assume that because they have always performed the activity internally, then it should remain that way. In many cases, closer analysis may reveal a signifi cant disparity between their capabilities and those of the world's best suppliers.

### Cost Analysis

All the actual and potential costs involved in sourcing the activity either internally or exter nally must be measured. This encompasses all the costs associated with the acquisition of the activity throughout the entire supply chain and not just the purchase price. It is important to consider costs right from idea conception, as in collaborating with a supplier in the design phase of the component, through to any costs (e.g., warranty claims) associated with the component once the completed product is being used by the final customer. The data requirements for this stage are quite formidable. Management must break down the organization's functional cost accounting data into the costs of performing specific activities. The appropriate degree of disaggregation depends upon the economics of the activities and how valuable it is to develop cross company comparisons for narrowly de fined activities as opposed to broadly defined activities.

Supply Management

As a result of increased outsourcing, organiza tions have become more dependent upon their suppliers, thus making SUPPLY MANAGE MENT a key success factor. Organizations have been adopting a range of relationship configur ations with suppliers and other organizations in order to reduce the risks associated with out sourcing. In particular, organizations that have adopted extensive outsourcing strategies have attempted to adopt collaborative arrangements with their key suppliers. The relationship con figurations adopted have been influenced by the type of product or service being outsourced and the number of capable suppliers that can deliver the product or service. In the case of a standard product or service that can be supplied by a number of external providers such as catering or security, the outsourcing organization is likely to employ a relationship bounded by explicit contractual safeguards such as price and pay ment terms, a short term perspective, and a clear definition of roles and responsibilities. Al ternatively, in the case of a more critical product or service, the outsourcing organization is likely to pursue a more collaborative relationship char acterized by relational mechanisms such as bi directional information sharing, a longer term perspective, and joint problem solving. These collaborative arrangements are sometimes re ferred to as "quasi integration" arrangements and can include strategies such as joint ventures, strategic alliances, franchising, and partnership sourcing.

See also *make or buy; strategic account manage ment; supply chain management; vertical inte gration*

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## overall equipment effectiveness

*Stuart Chambers*

The overall equipment effectiveness (OEE) measure is an increasingly popular method of judging the effectiveness of individual pieces of operations equipment. It is based on three aspects of performance:

- *the time* that equipment is available to operate;
- *the quality* of the product or service it produces;
- *the speed*, or throughput rate, of the equipment.

There is surprisingly little standardization in how capacity is measured. Not only is a reason ably accurate measure of capacity needed for operations planning and control, it is also re quired to decide whether it is worth investing in extra physical capacity such as machines. However, there is little unanimity in the way effective capacity has been defined or measured. One school of thought is that whatever capacity efficiency measures are used, they should be useful as diagnostic measures that can highlight the root causes of inefficient use of capacity. The idea of OEE has been proposed as a useful way of measuring capacity efficiencies.

OEE is defined as availability efficiency multiplied by performance efficiency multiplied by quality efficiency. Some of the reduction in available capacity of a piece of equipment (or any process) is caused by time losses such as the times when no work is scheduled on a process (either because there is no demand or statutory holidays are being taken), setup and changeover losses (when the equipment or process is being prepared for its next activity), and breakdown failures when the machine is being repaired. Some capacity is lost through speed losses such as when equipment is idling (e.g., when it is temporarily waiting for work from another process) and when equipment is being run below its optimum work rate. Finally, not everything processed by a piece of equipment will be error free. So some capacity is lost through quality losses. Conventionally this is stated as

$$\text{OEE} = a \times p \times q$$

For equipment to operate effectively, it needs to achieve high levels of performance against all three of these dimensions. Viewed in isolation, these matrices are important indicators of plant performance, but they do not give a complete picture of the machine's *overall* effectiveness. This can only be understood by looking at the combined effect of the three measures, calculated by multiplying the three individual metrics together. All these losses to the OEE performance can be expressed in terms of units of time – the design cycle time to produce one good part. So, a reject of one part has an equivalent time loss. In effect, this means that an OEE represents the valuable operating time as a percentage of the design capacity.

See also *aggregate capacity management; capacity management; capacity strategy; operations objectives; planning and control in operations*

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# P

## P:D ratios

*Nigel Slack*

The P:D ratio of an operation is the ratio of "demand" time (i.e., the time a customer must wait between asking for a product and receiving it) to the whole operation production cycle, P (i.e., how long the operation has to manage the flow of materials and information).

In a typical make to stock manufacturer such as those making consumer durables, customer demand time, D, is the sum of the times for transmitting the order to the company's order processing system, processing the order to the warehouse or stock point, picking and packing the order, and its physical transport to the cus tomer (the "deliver" cycle). Behind this visible order cycle lie other cycles. The "make" cycle involves scheduling work to the various stages in the manufacturing process. Physically, this in volves withdrawing materials and parts from input inventories and processing them through the various stages of the manufacturing route and the "purchase" cycle (the time for replen ishment of the input stocks) involving transmit ting the order to the supplier and awaiting their delivery. For this type of manufacturing the "demand" time that the customer sees is very short compared with the total throughput cycle, the sum of the deliver, make, and purchase cycles, P.

Contrasting with the make to stock company is the company which both makes and develops its products to order. Here D is the same as P. Both include an "inquiry" cycle, a "develop" cycle for the design of the product, followed by "purchase," "make," and "delivery" cycles.

Most companies operate with more than one P and more than one D. Reducing total through put time P will have varying effects on the time the customer has to wait for demand to be filled. For many customized products, P and D are virtually the same thing. The customer waits from the material being ordered through all stages in the production process. Speeding up any part of P will reduce the customer's waiting time, D. On the other hand, customers who purchase standard "assemble to order" products will only see reduced D time if the "assemble" and "deliver" parts of P are reduced and savings in time are passed on.

Generalizing, D is smaller than P for most companies. How much smaller D is than P is important because it indicates the proportion of the operation's activities that are speculative, i.e., carried out on the expectation of eventually receiving a firm order for the work. The larger P is compared with D, the higher the proportion of speculative activity in the operation and the greater the risk the operation carries. But the speculative element in the operation is not there only because P is greater than D; it is there because P is greater than D and demand cannot be forecast perfectly. With exact or close to exact forecasts, risk would be non existent or very low no matter how much bigger P was than D. When P and D are equal, speculation is eliminated because everything is made to a firm order. Reducing the P:D ratio becomes, in effect, a way of taking some of the risks out of manufacturing planning.

See also *build to order; dependent and independent demand; planning and control in operations; supply chain management*

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## Pareto analysis

*John Mapes*

Pareto analysis is a method of distinguishing what is important from what is less so in a process. It is used in many improvement techniques as the most effective method of prioritizing between the so called "vital few" issues and the "trivial many" issues. The Pareto approach is relatively straightforward and involves arranging information on the types of problem or causes of problem in a process into their order of importance. This can then be used to highlight areas where further decision making will be useful.

Pareto analysis is frequently used in INVENTORY MANAGEMENT, where it is also referred to as ABC analysis. It is used to classify stock items into groups based on the total annual expenditure for each item, although it is increasingly used in other areas of operations management such as QUALITY MANAGEMENT SYSTEMS. In most organizations the number of different items that must be stocked in order to run the business effectively is extremely large. It is unlikely to be economic or even practical to give the same high level of detailed attention to the control of every single stock item. What is needed is a method of identifying those items for which detailed control would produce the greatest payoff. The most commonly used way of achieving this is through Pareto analysis.

The first step in the analysis is to identify the factors that make a high degree of control of a stock item important. Two possible factors might be the rate at which the item is used and its unit value. For fast moving items with a high unit value then very close control is justified. On the other hand, with slow moving, low unit value items the cost of the stock control system may exceed the benefits to be gained so that only very simple methods of control can be justified.

One way of combining these two factors is to calculate for each stock item the total value of annual usage, called the annual requirement value (ARV):

$$\text{ARV} = \text{unit value} \times \text{annual usage}$$

If the stock items are then placed in descending order of ARV, the really important items will appear at the top of the list. If cumulative ARV is plotted against number of items, a graph known as a Pareto curve is obtained. A typical Pareto curve is shown in figure 1.

The precise shape of the Pareto curve will differ for each organization, but, typically, the first 20 percent of items stocked will account for approximately 80 percent of cumulative ARV. For a company with a stock list of 10,000 different items, this means that control of the top 2,000 items will give control of about 80 percent of total stock investment. These items are known as category A items and will require fairly sophisticated methods of control. The next 40 percent of items, called category B items, will, typically, account for a further 15 percent of cumulative ARV. Obviously the B items will need some measure of control, but much less precise methods than for category A can be used. The last 40 percent of items, called category C items, will account for a mere 5 percent of ARV. The C items are either very cheap or very slow moving and simple methods of stock control can be used. Even if this results in stocks of C items being rather greater than is strictly necessary, this will not increase total costs significantly and is likely to be much less than the cost of operating a more complicated system of stock control.

Other examples of the use of Pareto analysis in operations management include classifying QUALITY problems in order of their frequency of occurrence, failure modes in order of their impact on a system's performance (*see* FAILURE ANALYSIS), and work tasks in order of the total amount of time they occupy.

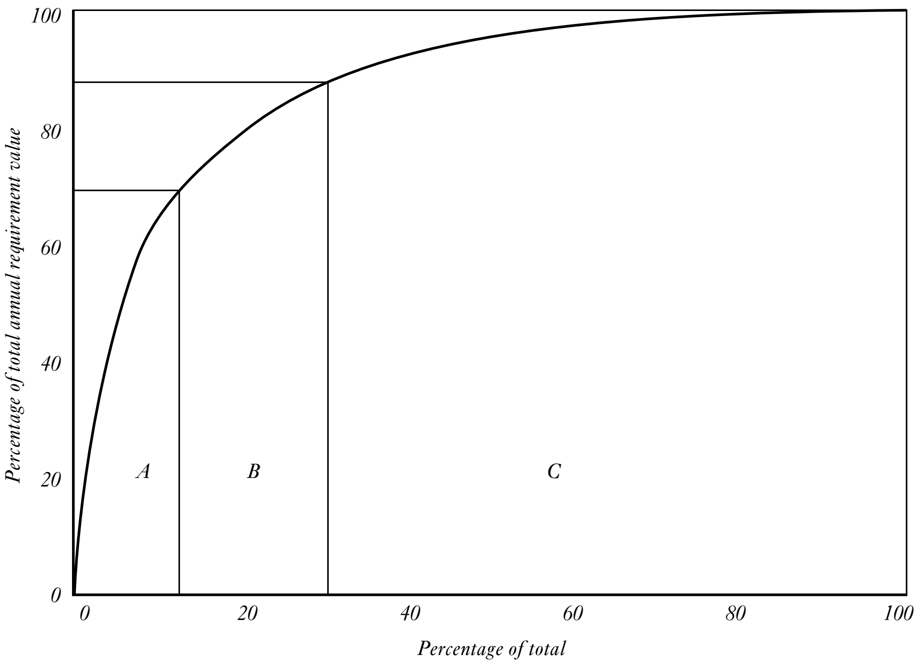


**Figure 1** A typical Pareto curve

See also *continuous improvement; quality tools; Taguchi methods; total quality management*

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## PDCA cycle

*Nigel Slack*

The PDCA cycle is frequently used in the con text of CONTINUOUS IMPROVEMENT. The repeated and cyclical nature of continuous im provement is well summarized by the PDCA cycle (or Deming wheel; *see* DEMING). The PDCA cycle is the sequence of activities that are undertaken on a cyclical basis to improve activities.

The cycle starts with the P (for plan) stage, which involves an examination of the current method or the problem area being studied. This involves collecting and analyzing data so as to formulate a plan of action that is intended to improve performance. Once a plan for improve ment has been agreed, the next step is the D (for do) stage. This is the implementation stage during which the plan is tried out in the oper ation. This stage may itself involve a mini PDCA cycle, as the problems of implementation are resolved. Next comes the C (for check) stage, where the newly implemented solution is evalu ated to see whether it has resulted in the expected performance improvement. Finally (at least for this cycle) comes the A (for act) stage. During this stage the change is consolidated or standardized if it has been successful. Alterna tively, if the change was not successful, the lessons learned from the "trial" are formalized before the cycle starts again.

See also *DMAIC cycle; quality; total quality management*

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## performance measurement

*Andrew Neely*

Performance measurement is the process of quantifying action, where measurement is the process of quantification and performance is the result of action. According to the marketing perspective, organizations achieve their goals by satisfying their customers with greater efficiency and effectiveness than their competitors. The terms efficiency and effectiveness have specific meanings in this context. Effectiveness refers to the extent to which customer requirements are met, while efficiency is a measure of how eco nomically the firm's resources are utilized when providing a given level of customer satisfaction. This is an important point because it not only identifies two fundamental dimensions of per formance, but also highlights the fact that there can be internal as well as external reasons for pursuing specific courses of action. The level of performance a business attains is a function of the efficiency and effectiveness of the actions it undertakes, and thus:

- Performance measurement can be defined as the process of quantifying the efficiency and effectiveness of action.
- A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of an action.
- A performance measurement system can be defined as the set of metrics used to quantify both the efficiency and effectiveness of actions.

These definitions highlight the fact that a per formance measurement system can be analyzed both at the level of the system and at the level of the individual performance measures that together constitute the system.

### The Performance Measurement System

Traditionally, businesses have used financially oriented performance measurement systems, relying on derivatives of measures, such as return on investment (ROI). By the time John son and Kaplan's *Relevance Lost* was published (1987), there was widespread dissatisfaction with these traditional, cost accounting based per formance measurement systems, not least be cause they were seen to encourage short termism and lack strategic focus. Additionally, they failed to provide data on quality, respon siveness, or flexibility, encouraged local opti mization, e.g., manufacturing inventory to keep people and machines busy, encouraged man agers to minimize the variances from standard rather than continually seek to improve, and failed to provide information on what customers wanted and what the competition was doing.

Many organizations are now actively involved in the process of reviewing their performance measurement systems, not simply to get a better means of monitoring performance, but also to enable them to (1) assess health, (2) stimulate learning, and (3) improve communication.

*Assessing health.* One of the primary roles of senior management in any organization is to keep track of whether the organization's re sources are being used in a way that will help it survive and prosper. Traditionally, financial measures of performance have been the tools used to do this, but increasingly senior managers are looking for a more rounded picture of the health of their businesses. As a result they are turning to measurement systems which combine the financial and non financial dimensions of performance. This trend is encapsulated by Kaplan and Norton's (1992, 1994) balanced scorecard, which is based on the assumption that an organization's measurement system should enable its managers to answer each of the following questions:

- How do we look to our shareholders (finan cial perspective)?
- What must we excel at (internal business perspective)?
- How do our customers see us (customer perspective)?

- How can we continue to improve and create value (innovation and learning per spective)?

Although popular, the balanced scorecard is not the only performance measurement frame work that is available. In the US and Europe the Malcolm Baldrige and the European Quality Awards, respectively, have proved to be popular ways of assessing the health of busi nesses (*see* BUSINESS EXCELLENCE MODEL; SELF ASSESSMENT MODELS AND QUALITY AWARDS).

*Stimulate learning.* Initially, BENCHMARKING was primarily seen as a means of determining an organization's competitive standing. More recently, however, the emphasis has shifted to benchmarking *practices* rather than perform ance. In large, multinational corporations this concept has important implications because, within such organizations, there is scope to transfer knowledge or learning from one part of the business to another. Having comparable measures of performance in different parts of the business simplifies the process of identi fying which knowledge could valuably be transferred.

*Improve communication.* It has long been recog nized that the affect of measurement is to stimu late action. The final way in which businesses are now seeking to use performance measures is as a means of communicating what they care about, thereby stimulating appropriate behaviors. (See "Step 5: Formula").

The Individual Performance Measures

Information is needed to specify a performance measure. This can be incorporated in a 10 step procedure.

*Step 1: Measure.* This step should fix the title of the measure. A good title is one that explains what the measure is and why it is important. It should be self explanatory and not include func tionally specific "jargon."

*Step 2: Purpose.* If a measure has no purpose then one can question whether it should be introduced. Hence in the second step the ration ale underlying the measure should be specified. Typical purposes include:

- To enable us to monitor the rate of improve ment, thereby driving down the total cost.
- To insure that all delayed orders are elimin ated ultimately.
- To stimulate improvement in the delivery performance of our suppliers.
- To insure that the new product introduction lead time is continually reduced.

*Step 3: Relates to.* If the measure being con sidered does not relate to any of the business objectives then one can question whether the measure should be introduced. Hence, in the third step, the business objectives to which the measure relates should be identified.

*Step 4: Target.* The objectives of any business are a function of the requirements of its owners and customers. The levels of performance the business needs to achieve to satisfy these object ives are dependent upon how good its competi tors are. Without knowledge of how good the competition is, and an explicit target, which specifies the level of performance to be achieved and a time scale for achieving it, it is impossible to assess whether performance is improving fast enough and hence whether the business is likely to be able to compete in the medium to long term. Typical targets include:

- "X" percent improvement year on year.
- "Y" percent reduction during the next 12 months.
- Achieve "Z" percent delivery performance (on time, in full) by the end of next year.

*Step 5: Formula.* This step is one of the most difficult to complete because the way perform ance is measured affects what people do. Take, for example, a measure such as value of new products won. This appears to be an appropriate measure for a sales manager. But if the formula is value, in terms of "$," the measure may encour age sales managers to seek large contracts rather than profitable ones. Hence perhaps the measure should be contribution, but the problem with this is that it might stop sales managers pursuing new business opportunities, even if they are of strategic significance.

There clearly can be problems if the formula is inappropriately defined, but it should be noted that the converse is also true. That is, it is often possible to define the formula in such a way that it induces good business practice.

*Step 6: Frequency.* The frequency with which performance should be recorded and reported is a function of the importance of the measure and the volume of data available.

*Step 7: Who measures.* This step should identify the person who is to collect and report the data.

*Step 8: Source of data.* This step should specify where the data come from. The importance of this question lies in the fact that a consistent source of data is vital if performance is to be compared over time.

*Step 9: Who acts on the data.* This step should identify the person who is to act on the data.

*Step 10: What do they do.* This step is probably the most important, not because it contains the most important information, but because it makes explicit the fact that unless the manage ment loop is closed (unless the measure stimu lates appropriate action), there is no point having it. It is not always possible to detail the action that will be taken if performance proves either to be acceptable or unacceptable, as this is often context specific. It is, however, always possible to define in general the management process that will be followed should performance appear either to be acceptable or unacceptable. Typical information for this step includes:

- Set up a continuous improvement group to identify reasons for poor performance and to make recommendations as to how perform ance can be improved.
- Publish all performance data and an execu tive summary on the shop floor as a means of demonstrating commitment to empower ment.
- Identify commonly occurring problems. Set up review team, consisting of sales, develop ment, and manufacturing personnel, to estab lish whether alternative materials can be used.

These steps can be incorporated into a perform ance record sheet which provides a structured way of recording all the data necessary to specify a performance measure. In reality, of course, the act of specifying individual performance meas ures is but an element of the process of develop ing a performance measurement system.

See also *manufacturing strategy; operations activ ities; operations objectives*

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## physical distribution management

*Christine Harland*

Physical distribution is a concept or approach to managing the finished goods inventory of the firm. Typically it includes transportation, ware housing, inventory, and order processing func tions. It can also refer, more simply, to the storage of goods and their transport from one firm to another in the supply chain. Most authors on physical distribution management now use the term LOGISTICS to include consid eration of business processes and information flows as well as physical flows.

Many of the systems for physical distribution are "multi echelon" systems with storage at dif ferent points in the supply chain. For example, a manufacturer stores products in its own ware house. From there the products may be distrib uted to a regional warehouse for a retailer. Regional warehouses have several benefits. First, they act as an intermediate point which is located closer to the retailer than their manufac turing site, therefore facilitating quicker deliv ery. Second, they enable the manufacturer to deliver to a limited number of customer loca tions, rather than do store by store delivery. Third, the retailer has to request stocking up from only one source of supply. The introduc tion of a warehouse stage in the physical distri bution network can therefore simplify communications and routes.

However, warehouse locations have costs. These include the opportunity cost of the capital tied up in the inventory contained in them, the cost of the facilities themselves (e.g., lease costs), the cost of running the facilities (e.g., labor, heating, security, lighting), and the cost of inventory loss (e.g., obsolescence, deterioration, etc.). Therefore, warehouse decisions involve consideration of the costs and benefits as well as the location (*see* INVENTORY RELATED COSTS).

As well as decisions on the structure of the physical distribution system, in terms of the number, size, and location of distribution centers, decisions have to be made on the mode of transport to use to move goods between the nodes in the network. The modes of transport available to the distribution manager are: road, rail, water, air, or pipeline.

Each of these modes has certain characteristics that affect its suitability. For example, air transport is expensive, limited in the space available (in terms of the capacity of the aircraft and the number of flights scheduled on a particular route), and in access to suitable airports. Air transport is therefore typically used for high value, low volume items, such as jewelry or fresh lobsters. Conversely, bulk raw materials are often transported using slower, cheaper forms of transport such as water or rail. Some hazardous items, such as nuclear waste, have to be transported in special containers and are only allowed to use certain routes at certain times.

The choice of transport mode is determined not only by cost but also by physical product characteristics. It is not possible to transport discrete parts by pipeline because they do not flow, whereas a pipeline is an option for liquids such as oil and chemicals and for gases such as domestic supply gas.

The choice of transport mode is usually determined by the relative importance of delivery speed and reliability, quality and perishability (or contamination), costs, and flexibility (including ease of access, ease of movement, and capacities).

See also *capacity strategy; inventory control systems; location; materials management; supply chain dynamics; supply chain management*

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## planning and control in operations

*Nigel Slack*

Planning and control processes attempt to reconcile internal operations activities with the demands of customers. The generic constraints within which the planning and control activity takes place include:

- *Cost constraints*: Products and services must be produced within an identified cost.
- *Capacity constraints*: Products and services must be produced within the designed capacity limits of the operation.
- *Timing constraints*: Products and services must be produced within the time when they still have value for the customer.
- *Quality constraints*: Products and services must conform to the designed tolerance limits of the product or service.

The division between planning and control is not clear, either in theory or in practice, but there are some general features that help to distinguish between them.

- A *plan* is a formalization of what is intended to happen at some time in the future. It does not guarantee that an event will actually happen, but is a statement of intention based on expectations concerning the future. When operations attempt to implement plans, things do not always happen as expected. For example, customers change their minds about what they want and when they want it, suppliers may not always deliver on time, machines may fail, and staff may be absent through illness. For any of these reasons, and many others, the plan may not be carried out.

- *Control* is the process of coping with these changes, which may mean that plans need to be redrawn in the short term, and that an "intervention" will need to be made in the operation to bring it back "on plan." Control makes the adjustments which allows the op eration to achieve the objectives that the plan set, even when the assumptions that the plan made do not hold true. We can define a plan as an intention and control as the driving through of the plan, monitoring what actually happens and making changes as necessary.

The nature of planning and control differs in the long, medium, and short term. In the very long term operations managers make plans concern ing what they intend to do, what resources they need, and what objectives they hope to achieve. The emphasis is on planning rather than control because there is little to control as such. They will use forecasts of likely demand which are described in aggregated terms. Similarly, the resources will be planned in an aggregated form. In carrying out their planning activities the operations managers will place heavy em phasis on achieving financial costs and revenue targets.

Medium term planning and control is con cerned with both planning in more detail and replanning if necessary. It looks ahead to assess the overall demand that the operation must meet in a partially disaggregated manner. Similarly, resources will be set at a more disaggregated level. Just as important, contingencies will have been put in place which allow for slight devi ations from plans. These contingencies will act as "reserve" resources and make planning and control easier in the short term.

In short term planning and control many of the resources will have been set and it will be difficult to make large scale changes in resour cing. However, short term interventions are possible if things are not going to plan. By this time demand will be assessed on a totally disag gregated basis. In making short term interven tion and changes to plan, operations managers might be attempting to balance the various aspects of performance on an ad hoc basis. It is possible that they will not have the time to carry out detailed calculations of the effects of their short term planning and control decisions on all these objectives. However, a general under standing of priorities will form the background to their decision making.

See also *capacity management; dependent and in dependent demand; finite and infinite loading; push and pull planning and control; scheduling; sequen cing*

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**predetermined motion time systems**

*John Heap*

Predetermined motion time systems (PMTS) are WORK MEASUREMENT systems based on the analysis of work into basic human move ments, classified according to the nature of the movement and the conditions under which it is made. Tables of data provide a time, at a de fined rate of working, for each classification of each movement. The first PMTS (since desig nated as "first level" systems) were designed to provide times for detailed manual work and thus consisted of fundamental movements and associated times. Large amounts of research, data collection, analysis, synthesis, and valid ation are required to produce PMTS data and the number of such systems is very low. "Higher level" systems have since been de vised, most commonly by combining these fun damental movements into common, simple manual tasks. Such higher level systems are designed for faster standard setting of longer cycle activity.

Criticisms of PMTS relate to their inability to provide data for movements made under "un natural" conditions (such as working in cramped conditions or with an unnatural body posture) or for mental processes and their difficulty in coping with work that is subject to interruptions. However, various systems have been derived for "office work," which include tasks with a simple and predictable mental content.

Many PMTS are proprietary systems and users must either attend a designated and ap proved training course and/or pay a royalty for use of the data.

See also *analytical estimating; time study; work study; work time distributions*

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## preventive maintenance

*Nigel Slack*

Preventive maintenance aims to prevent asset/facility failures caused by time dependent factors such as component wear. Most oper ations plan their maintenance to include a level of regular preventive maintenance which gives a reasonably low but finite chance of breakdown. Usually the more frequent the preventive main tenance episodes, the fewer the chances of a breakdown. The balance between preventive and breakdown maintenance (intervening only when failure occurs) is set to minimize the total costs associated with care and breakdown. Infre quent preventive maintenance will cost little to provide but result in a high likelihood (and therefore cost) of breakdown maintenance. Con versely, very frequent preventive maintenance will be expensive to provide but will reduce the cost of having to provide breakdown mainten ance. The total cost of maintenance is held to minimize at an "optimum" level. This optimum level indicates the recommended frequency of preventive maintenance.

However, this conventional representation of maintenance related costs, although conceptu ally elegant, may not reflect reality in some operations and is being challenged by some aca demics. For example, the cost of providing pre ventive maintenance may not increase with increasing frequency of intervention as steeply as assumed. The relationship between prevent ive maintenance frequency and cost assumes that it is carried out by a separate set of people (skilled maintenance staff) whose time is sched uled and accounted for separately from the "op erators" of the facilities. Furthermore, every time preventive maintenance takes place, the facilities cannot be used productively, which is why the relationship is often taken to increase marginal costs, because the maintenance epi sodes start to interfere with the normal working of the operation. Yet in many operations, at least some of the preventive maintenance can be per formed by the operators themselves (which re duces the cost of providing it) and at times that are convenient for the operation (minimizing disruption). In addition it can also be argued that the cost of breakdowns could be higher than is traditionally assumed. Here the argument is that unplanned breakdowns may do more than necessitate a repair and stop the operation; they can take away stability from the operation, which prevents it being able to improve itself (*see* DELIVERY DEPENDABILITY). The combin ation of these two adjustments to conventional preventive maintenance has the effect of moving the "optimum" level of maintenance interven tion significantly toward the use of preventive maintenance rather than run to breakdown maintenance.

See also *condition based maintenance; reliability centered maintenance; total productive mainten ance*

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## PRINCE 2

*Harvey Maylor*

Successor to PRINCE – PRojects IN Controlled Environments – PRINCE 2 is a standardized set of processes for PROJECT MANAGEMENT. It originated in the IT sector (particularly UK government IT procurement) but is now being used worldwide, often in combination with one of the bodies of knowledge (*see* PROJECT MANAGEMENT BODIES OF KNOWLEDGE). The processes specify many aspects of how the project will be organized and controlled, including the documentation, the structures, and the reporting frameworks. For more information, see http://www.prince2.com.

See also *network techniques; work breakdown structures*

## principles of motion economy

*John Heap*

The principles of motion economy are guidelines to be used when examining and designing workstation and workplace layouts and during METHOD STUDY. They are simple and empirical hints on work design that are based on a combination of simple ergonomic principles and common sense. They relate to both the design of the workplace and the design of the work. Thus, for example, they advise that gravity should be used, where possible, to deliver materials to their point of use and to remove completed work. They include the characteristics of easy movement which suggest that working methods and workplaces should be designed such that the motion patterns required of workers can comprise movements that are minimum, symmetrical, simultaneous, natural, rhythmical, habitual, and continuous.

See also *ergonomics; layout*

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## process layout

*David Bennett*

A process (or functional) layout is one of the three basic options for laying out facilities to produce goods or deliver services, the other options being FIXED POSITION LAYOUT or PRODUCT LAYOUT. A fourth alternative, the CELL LAYOUT, is actually a hybrid facility arrangement which combines some of the principles of fixed position and product layouts.

The term "process layout" implies that all similar production processes are grouped together in the same department or area. This approach to laying out facilities can be applied to component production or assembly. In component production the "processes" might be different manufacturing processes such as milling, drilling, turning, grinding, plastic molding, etc. In assembly the use of a process layout might involve having separate areas for producing different subassemblies, final assembly, testing, packing, etc. The use of process layouts is most common in batch operations where batches of parts (or perhaps customers in the case of services) are routed from one process area to another, where a single production operation, or perhaps a limited number of operations, is carried out. Examples in service provision are less easy to identify, but in retailing the arrangement of shops in a high street could be considered to be a process layout since they each sell common products (bread, vegetables, hardware, etc.).

There is some debate concerning the relative advantages and disadvantages of process layouts. They are very popular, but this could simply be based on the historical situation where similar machines were grouped together because they were driven from a common power source. Advantages include the opportunity for specialized supervision, and there is a degree of flexibility involved because the priority of batches can be changed while they are being progressed through the production system. There are, on the other hand, a large number of disadvantages including high work in progress levels, frequent setups, extensive material movement, and long throughput times.

It is sometimes argued that process lay outs enable greater economies of scale to be achieved. However, this is only true relative to using a fixed position layout; a product layout offers even greater scale benefits. The use of group technology and a cell layout can overcome the disadvantages associated with process layouts.

When process layouts are used they should be designed in such a way that they offer the best "efficiency." This can be achieved by insuring that total material movement (or cost of material movement) is minimized. Alternatively, or add itionally, other factors may be taken into account such as the movement of workers or the need for information to be exchanged between process areas. A number of computer software packages are available that are designed to calculate the "optimum" process layout; these include CRAFT (computerized relative allocation of fa cilities technique) and CORELAP (computer ized relationship layout planning). The input to these packages would normally include such data as the number of material movements per unit of time between the various processes and the cost of movement per unit of distance. Secondary factors such as the desired "closeness" of pro cesses for the purpose of information exchange etc. can be represented on a "relationship chart."

One of the problems with using such tech niques is that they only provide the solution to a "static" problem (i.e., for a particular mix of products and fixed operation sequences). In practice, however, the layout problem is a dy namic one because the situation is continuously changing and the "best" solution today may not be so tomorrow. For this reason "simulation" is growing in popularity as a tool for analyzing and designing process layouts (and indeed any type of layout). A computer simulation enables changes to a layout, or its operating information, to be modeled so that the effect can be seen almost instantaneously. Moreover, a "visual interactive" simulation will allow the designer to see a graphic representation of the layout on a computer screen and to quickly determine the effect of any modifications made.

See also *bottlenecks; business process redesign; div ision of labor; group working; layout; simulation modeling; work organization*

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## process mapping

*John Heap*

Process mapping (or charts) describes processes in terms of the activities within the process and how they relate to one another (this may also be called process blueprinting or process analysis). Process maps are a simple shorthand means of recording the details of processes, often for sub sequent analysis. Because they are in common usage, they are seen as a common "language" which facilitates analysis. There are several types of process maps, each designed for a particular level or stage of analysis. Their variety and flexi bility mean that they can be used at the worksta tion and workplace level and at the wider system, process, or procedure level. All use a common core set of symbols, though some have additional symbols for specific and specialized process steps. The common symbols (of which there are only five) were first promulgated by the American Society of Mechanical Engineers and have become known as the ASME symbols.

The simplest process map is known as an outline process map. It records an overview of a process by recording only those steps of a process that can be represented by the ASME symbols of operation (which is a main process step that normally results in some change to the material being processed, or significant effort on behalf of the operator) and inspection (which is a verification of quality or quantity). This is often a useful first step to identify key areas of concern before recording (part of) the process in more detail. In a "full" process map, where all sym bols are used, it is common to chart the process from the "viewpoint" of the material being pro cessed, the worker carrying out the work or, less commonly, a piece of equipment. Thus, the same symbols can be used in different ways. As a simple example, a piece of equipment can be represented on an equipment type flow process chart as a "delay" (because it is not in use), while a material type flow process chart would show the material being transported to the next workstation, and a human type chart could show the operator involved in another operation on another machine. The chart to be used may be determined by the purpose of the investigation or by the relative costs involved in the process – a highly capital intensive process may focus more attention on the equipment being used.

Process maps or charts may also be used at a more micro level of analysis. An example is the "two handed process chart" that records the motions performed by both hands during a task. The sequence of motion of each hand is mapped using the same symbols as before. There are slight changes to the meaning of the symbols, however. The delay symbol is used to indicate that the hand is waiting to carry out its next task. The storage symbol is used to indicate that the hand is holding on to a piece of material or a document. Usually two handed process charts are drawn on a preformatted diagram.

See also *business process redesign; layout; method study; service design*

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## process technology

*Michael Lewis*

There is a widely held perception that, regard less of the marketplace, competitive business processes exploit technology. In fact it could be argued that the very idea of "business processes" only came to prominence as (information) tech nology allowed for the possibility of integrating previously disparate productive activities into "seamless" value chains. Therefore, process technology can be defined as the application of scientific knowledge to processes involved in the transformation of:

1 *material inputs*: involves either physical state (bent, cut etc.) or physical location (ship ping, storage etc.) outcomes.
2 *information inputs*: involves either analytical (market research, systems control etc.) or transactional (communications, ownership etc.) outcomes.
3 *customer inputs*: leads to either physiological (surgical procedure, renal dialysis etc.) or psychological (cinema entertainment, theme park ride etc.) outcomes.

Process technologies will often integrate more than one type of input. For instance, the systems used at the check in gate of airports integrate the processing of airline passengers (customers), details of their flight, destination and seating preference (information), and the number and nature of their items of luggage (materials). This example also illustrates that the input/output pairings described above are not exclusive. For instance, an airport processes customers with the intent of beginning the process of changing their physical location.

Any historical perspective on industry imme diately highlights that the relationship between processes and technology predates the IT revo lution. Mass manufacturing, for instance, is in timately linked with the appliance of scientific knowledge to production problems and has pro duced a distinct category of "processing" tech nologies that help to define the nature of the business. Regardless of whether it is rollers flat tening ingots of steel in a steel plant, injection molders creating plastic toys, or coating ma chines spreading precise amounts of chocolate over candy bars, these are all examples of "tech nology acting as part of value creating or trans formation processes." The same definition also applies in some circumstances to services. Many traditionally labor intensive operations, such as retail bank back offices for instance, are adopting "manufacturing type" strategies, reliant upon sophisticated volume processing equipment. At the same time it is not hard to justify the argu ment that there has been a technology revolution in the last two or three decades. For instance, in the US, where arguably the digital revolution has been most profound, between 1978 and 1985 the proportion of capital equipment stock tripled from 1.8 to 7.8 percent. By 1988, invest ments in hardware alone had reached $35.7 bil lion (and IT in general accounted for 42 percent of total business expenditure), and by 1998, it had reached $95.7 billion.

Both manufacturing and SERVICE OPER ATIONS are increasingly reliant upon a whole range of different technologies and even a superficial review of capital investment in most organizations reveals that information and inter connection technologies are often the most significant investments being made. Three attri butes provide a useful heuristic for characteriz ing different forms of process technology.

### Scale

Determining the overall size of operations and the scale of capacity increments in relation to market demand and forecast changes in demand involves critical managerial decisions and, cor respondingly, it is crucial to recognize how indi vidual units of technology contribute to the overall capacity of an operation: by adopting technologies with different scale characteristics, an operation can significantly affect its perform ance. Process technologies in commodity indus tries like steel or chemicals often benefit from scale and therefore tend to come in large cap acity increments whereas other technologies have a much smaller natural scale.

### Degree of Automation

The relative balance between human and tech nological effort in a unit of technology is usually referred to as its capital intensity or degree of automation. The strong drive toward greater automation in both manufacturing and service operations is largely related to the desire to op erate faster and/or deliver reduced direct labor costs. However, the true impact of automation needs to be assessed in broader terms. There are a number of different factors that need to be considered before automating, including: the degree of technical support required, the scope for future improvements, and the flexibility and dependability of the process.

### Degree of Coupling

As IT has become ever more affordable and readily available, its use in operations applica tions became more prevalent. In manufacturing, for instance, a great deal of emphasis was placed on advanced manufacturing technologies (AMT) and flexible manufacturing systems (FMS) as a response to competitive cost and quality pressures. Much of the advance in these technologies has come from the physical and/or managerial coupling of activities that were pre viously separate units of technology. At its sim plest, increasing coupling removes much of the fragmentation caused by physical or organiza tional separation. So, for example, a speed revo lution has taken place in many financial services; a mortgage application is now usually accepted provisionally over the phone, whereas once it took three weeks of paperwork. This change can be directly attributed to the increased coupling of technology in financial services whereby individuals or teams can manage all aspects of a service delivery process.

The automation, scale, and coupling dimen sions are all strongly related. For example, the larger the unit of capacity, the more likely that it is capital rather than labor intensive, which gives more opportunity for high coupling between its various parts. Conversely, small scale technolo gies, combined with highly skilled staff, tend to be more flexible than large scale, capital intensive, closely coupled systems. As a result these systems can cope with a high degree of product variety or service customization (i.e., bespoke tailors and boutique strategy consulting firms). Conversely, where flexibility is of little importance (with standardized, low cost products such as indus trial fastenings, or a mass transaction service such as letter sorting) but achieving dependable high volumes and low unit costs is critical, then these inflexible systems come into their own.

See also *advanced manufacturing technology; flex ible manufacturing system; implementing process technology; service technology*

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## process types

*Stuart Chambers*

Manufacturing operations are made up of transformation processes which are conventionally classified according to their VOLUME and VARIETY characteristics. Some operations produce products of a single type in very large volumes with little or no choice of DESIGN or product range. At the opposite extreme, operations may provide unique or highly customized outputs which exactly meet the specific requirements of individual customers. In practice, most operations fall between these extremes, producing some range of designs of products or services in a variety of volumes, and usually having to respond to changes in mix of outputs as market requirements vary.

The necessity for some classification of processes derives from the assumption that no single manufacturing process could ever be appropriate for all circumstances. For example, processes designed to produce efficiently high volumes of single products will usually have little flexibility, in that it would be both expensive and time consuming to adapt them to make other products. Conversely, processes designed for low volume, high variety products or services are designed to achieve fast, low cost changeovers from one product type to another. From this it is intuitively reasonable to suppose that different generic designs of manufacturing process (the term process choice is commonly used) for products with different volume and variety characteristics will be required.

The names adopted for these general manufacturing process types can have slightly different meanings in different parts of the world. In particular, North American terminology uses some classifications which are different to those in Europe. Similarly, the colloquial use of these process names may also in practice differ between individual industries or plants. The underlying principle of all process classifications, however, is that transformation processes should be designed to best match the volume and variety characteristics of the required outputs.

In order of increasing volume and decreasing variety, the conventional manufacturing process types are as follows:

- project processes;
- jobbing processes;
- batch processes;
- line processes;
- continuous processes.

### Project

In addition to representing an emerging subcategory of operations management as a whole, the term "project" is also used to describe an extreme form of process (*see* PROJECT MANAGEMENT). At one time those processes which were categorized as "projects" were associated with the construction industry and large, complex engineering tasks. The general characteristics of these projects are that they have a relatively large work content, a diverse and complex set of inputs, and a long time scale often extending over years from design to completion. These types of project may be physically large, necessitating a FIXED POSITION LAYOUT.

More recently, it has become accepted that the use of project processes and principles has spread beyond these industries to encompass both services and complex, but more "portable," products. Examples include software development, international marketing campaigns, privatization projects by government, and television program production. However, all project processes deal with very low volume and high variety.

### Jobbing

Like project processes, jobbing processes produce products or services tailored to suit the requirements of individual orders, in very small quantities, in a form that is not expected to repeat. However, smaller scale, reduced work content, and lower complexity of jobbing often allows the work to be completed in fewer stages. Because transport of the product is possible, all stages of manufacture can be undertaken by a single operative at specialized workstations or machines which are often arranged in a PROCESS LAYOUT, although fixed position layouts may also be used. As a result, the operatives will usually possess wide skills (to operate a range of technologies) and may be given considerable responsibility in planning and executing their tasks.

Jobbing is used in most sectors to satisfy customers who want specially made products or services, but usually cost is higher than more standardized products because of higher labor cost and lower equipment utilization compared to higher volume processes. Jobbing businesses, therefore, usually compete by providing high levels of flexibility, quality, or responsiveness. Jobbing businesses or departments are sometimes referred to as job shops, but in North America this term may also encompass batch processes.

### Batch

Most operations are designed to provide an ongoing output of repeating products to satisfy their markets, at such a level of demand that cannot be economically satisfied by jobbing processes. Batch processes are frequently used to cover this middle ground of volume and variety so that labor and general purpose equipment are shared across the range of products. This involves the transformation together of predetermined quantities of a product, known as a batch or lot (hence the name batch process). Usually the stages of manufacturing are clearly separated, and may be located in separate specialized areas, usually in a process layout form, although at the higher volume end of batch manufacturing PRODUCT LAYOUT may be used.

Each of the stages of manufacture begins by setting up the equipment in preparation for the processing of the complete batch of the product. Because these setups take time and cost money, operations will usually plan to transform many items at a time, to minimize the unit cost (*see* ECONOMIC ORDER QUANTITY; SETUP REDUCTION).

The operatives at each processing stage may be skilled only in one part of the process, and because all the items in a batch are processed at separate stages, periods of added value processing are separated by periods of non added value movement and delay. This results in the intermittent flow of materials and is associated with high levels of work in progress. The ratio of total added value processing time to total time in the system (throughput efficiency) is characteristically very low in batch manufacturing. This may be considered unacceptable where markets require fast response from order to delivery (*see* TIME BASED PERFORMANCE).

Despite this, batch processing remains the most common form of process in manufacturing. The main advantages are that this approach has the flexibility to allow a very wide range of outputs to be produced in differing volumes, while simultaneously maintaining high levels of utilization.

### Line

Where volumes are sufficiently high, line processes (sometimes referred to as "flow" or "mass" processes) are often preferred, particularly where high volume involves repetitive but large work content tasks such as the assembly of complex automotive, electrical, or electronic products.

The underlying principle of line processes is that transformation is divided into steps that can be completed in similar times (*see* LINE BALANCING), which are then usually arranged as a product layout. When operating, the transformed resources are moved progressively along the stages of the process (sometimes known as stations). For much of the time in the process, value is being added to products and so throughput efficiency can be high, work in progress inventory low, and output consistent and predictable. There is a smooth flow of movement through the process. In its classic form, line process produces only one product type at a consistent rate, regardless of fluctuations in market demand, which must be provided through the use of inventory. Because variety is low, setups are infrequent.

Line processes may be highly capital intensive, comprising many dedicated technologies and materials movement systems. In these cases, the rate of transformation is usually predetermined and controlled by the technology. Such systems, known as machine paced lines, are often highly automated, but where human effort is required, each task must be completed within the cycle time.

Other types of line process are designed to allow operators some control over the output rate: these are known as unpaced or worker paced. In some cases, this simply gives the team of operators control over the speed of the technology, such as the conveyors in assembly lines; in other cases, there is less use of technology, and the transformation is largely manned, with materials being passed from operator to operator by hand.

### Continuous Process

High volume processing of bulk standard materials such as powders and liquids requires dedicated equipment, configured in a product layout to complete the task in a fixed sequence. Such processes are termed continuous processes. They are often dominated by the technology of transformation with little labor input and little contact between the operatives and the materials. Labor may be predominantly used for the control and monitoring of the process, often through computer systems. This implies that some technical skills and knowledge will be needed.

Rather confusingly, this type of manufacturing is sometimes referred to simply as process manufacturing, and some industries are referred to as process industries. This can be misleading, as they often involve the batch production of liquid or powder products, without the degree of dedication and absence of setups that are associated with continuous processes.

### Process Choice

A key concept in the classification of manufacturing processes is that each process type occupies an overlapping but distinct position on a volume–variety continuum from low volume–high variety through to high volume–low variety. The volume–variety characteristics of a process type then imply a set of properties that define the design, planning, and control of the process. This is the basis of process choice which, at one level, can be seen as a predictive instrument inasmuch as it indicates the nature of operations management as being contingent upon the process type used. So, for example, as processes move from project through to continuous, material flow goes from intermittent to continuous, PROCESS TECHNOLOGY goes from general purpose to dedicated, staff skills go from task oriented to system oriented, planning decisions go from being concerned with timing issues to being concerned with volume issues, control goes from detailed to aggregated, and so on. At another level, process choice can be seen as a diagnostic tool which detects inconsistency in operations management practice. So, if an operation is charted in terms of its properties and activities, they should all be at the same point on their continuum that characterizes the spectrum from project to continuous processes. Any deviation implies a lack of internal coherence in the operation.

See also *hierarchy of operations; layout; transformation model*

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## product architecture

*Pamela Danese*

The product architecture is the scheme by which the functional elements of a product are associated with its physical components. The function of a product is simply "what it does." Such functionality can be divided into elements that are the individual operations and transformations contributing to the overall performance of the product (Ulrich and Eppinger, 2000). These functional elements are implemented by physical components that are the separable physical parts composing the product. The product architecture is characterized by: (1) the mapping between functional elements and phys ical components and (2) the specification of the interfaces among interacting physical compon ents (Ulrich, 1995). Generally, the mapping be tween functional elements and physical components may be one to one, when every functional element corresponds to a single phys ical component and vice versa; many to one, when more functional elements correspond to a single physical component; or one to many, when a single functional element corresponds to more physical components.

The specification of the interfaces among interacting components concerns the inter actions across the interfaced components and the mating geometry among them in the cases where there is a geometric connection. Interfaces are called coupled if a change made to one phys ical component requires a change to the other interacting physical components in order for the overall product to work correctly. Otherwise, interfaces are decoupled. On the basis of these elements, two typologies of product architecture can be defined (Ulrich, 1994):

1. modular architecture, characterized by (a) a one to one mapping between functional elements and physical components and (b) decoupled interfaces among physical com ponents (in this case physical components are called modules);
2. integral architecture, characterized by (a) a complex (non one to one) mapping and/or (b) coupled interfaces among physical components.

See also *new product development process; product design process; product modularity*

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## product design process

*James Moultrie*

The product design process is the set of parallel and sequential technical activities by which an idea is translated into a manufactured reality. This process is distinct from the business pro cess of new product development(*see* NEW PRODUCT DEVELOPMENT PROCESS), which also encompasses the broader organizational aspects of bringing products to market. There are many representations of the product design process that aim to provide structure to the complex processes of product creation in order to increase the likelihood of the result being a (commercial) success. Descriptive models of the product design process aim to reflect reality and describe the sequence of events that typically occur. Such models tend to be solution focused, based around the proposal of a potential solution that can subsequently be evaluated, refined, and developed. A typical descriptive process is rela tively abstract and would include elements such as "exploration, generation, evaluation, and communication."

In contrast, prescriptive representations of the product design process aim to prescribe an ideal ized sequence based on views of "good prac tice." Such prescriptive processes tend to be more problem focused with a strong emphasis on the analysis and understanding of perceived problems, before proposing potential solutions. Here, a critical element is the clear definition of perceived needs in the form of a specification. A typical descriptive process includes sufficient detail and structure for the practitioner to follow if desired.

Descriptive product design processes tend to more accurately reflect the iterative nature of product design and the importance of "straw man" solutions to test and learn from. In prac tice, however, problem focused models tend to represent a more pragmatic approach to the in dustrial community. The most effective product design processes combine a descriptive element in their overall philosophy and prescriptive aspects mandating essential activities. Key elem ents of the product design process include the identification and specification of requirements, the creation of concepts, the selection of a preferred embodiment, and the implementation of the detailed engineering.

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## product families

*David Bennett*

The idea of grouping products or component parts into families arose in response to the problems associated with batch operations using a PRODUCT LAYOUT. One of the major limitations of this traditional approach to production relates to the frequent and time consuming resetting that needs to take place when facilities are changed over between the production of different batches of products or parts. This results in a significant loss of capacity and also causes management to produce larger batches than may be required to satisfy immediate demand.

A major cause of long resetting times is the dissimilarity of design features, and hence processing operations, across the whole range of products and parts being made in any particular production plant. In conventional batch operations, production planning does not take design features into account when a facility is changed from one product to another. As a result, the sequence in which batches are processed is, from a design point of view, random and the changeover time is consequently maximized.

The identification of families of products and parts addresses this problem by taking design into account in the production planning process. A family is simply a group of products that exhibit the same or similar design characteristics. Hence there is some commonality of processing operations which results in shorter overall setting times when they are produced on the same machine or group of facilities.

Families are normally created using coding and classification (*see* CELL LAYOUT) where products or parts are identified by a numerical or alphanumeric coding system. Using this approach, the identification numbers of products are actually coded descriptions of their design, which can be used to sort them into groups, or "families," for the purpose of processing on a common set of facilities.

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## product layout

*David Bennett*

A product (or operation sequence) layout is one of the three basic options for laying out facilities to produce goods or deliver services, the other options being a FIXED POSITION LAYOUT or PROCESS LAYOUT. A fourth alternative, the CELL LAYOUT, is actually a hybrid facility arrangement which combines some of the principles of fixed position and product layouts.

As its name implies, a product, or operation sequence, layout is determined by the design of the product. In other words, it is where machines, equipment, and workplaces are arranged according to the sequence of operations required for a defined product. In this context the product could be the complete end product, a subassembly, or a component part.

Product layouts usually take the form of lines with unidirectional flow. Although cell layouts are also based on the design of products, they differ in that the operation sequence and flow direction can usually be varied.

There are two basic types of product layout. First, there is the assembly type, where at each workstation materials are added and resources applied to produce discrete end products. Second, there is the analytical (or "disassembly" type) where a single raw material input is separated into parts and subsequently processed. Examples of this second type are oil refining and abattoirs; in fact, Henry Ford revealed that his idea of building the Model T car using an assembly line came from seeing lines used in the Chicago meat packing industry.

There is a third type of product layout, the transfer line, where there is only one material input at the beginning of the line and its form is modified, usually by machining processes, as it stops at each workstation. However, this is con ceptually similar to the assembly type and can be designed in the same way.

Some of the advantages of product layouts are that they require relatively infrequent setups, involve low work in progress levels, have min imum material movement, need lower labor skills, and can be easily automated. They gained great popularity in the early part of the twentieth century after their possibilities for improving efficiency were demonstrated by Henry Ford. More recently, however, a number of problems have come to light. Among these are the "human" problems of recruitment difficulties, absenteeism, high turnover, and so on, and the "physical" problems of high capital cost, risk of stoppage (if one machine fails the whole line stops), and inflexibility (in terms of product variety and operation sequence).

The design of product layouts is very import ant because they are normally used in high product volume situations where there is price competition in the marketplace. Efficiency is therefore a prime consideration and there is a need to minimize the amount of idle time at each workstation. The approach used in their design is usually termed LINE BALANCING, which as well as minimizing idle time seeks to spread it evenly across workstations. A further consider ation is to minimize the system loss that results from differences between the operators' work times and the fixed cycle time of the line (*see* WORK TIME DISTRIBUTIONS).

A popular belief with product layouts is that they can only be used in connection with highly standardized products. This may have been true at one time, but now a wide variety of different products can be made using variations on the basic product layout known as multimodel and mixed model lines. One of the difficulties with building a wide variety of products on a line was the need to schedule the correct item of material to the correct workstation at the correct time. However, this can now be achieved relatively easily under computer control.

See also *balancing loss; bottlenecks; business process redesign; layout*

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## product modularity

*Pamela Danese*

Although the subject of a great deal of recent hyperbole, the concept of product modularity is not new: the first modular computer, for in stance (System/360 – IBM), was created in 1964. Similarly, in other industrial sectors, such as in the automotive industry, product modularity has been applied for many years. According to Ulrich (1994), product modularity depends on two product characteristics: (1) simi larities between physical and functional design, and (2) minimization of incidental interactions and of coupled interfaces among physical components.

The function of a product can be divided into a set of functional elements, each of which rep resents an individual operation or transform ation. For example, the functional elements of an automatic machine for sheet metal bending might include the loading of the sheet to be bent, the bending of the sheet, and its unloading. The degree to which each of these functional elements is implemented by separate physical machine components contributes to its degree of modularity. For example, with a machine of three distinct physical elements (i.e., loading, bending, and unloading units), the product will be more modular than if it comprised two physical elements, one for loading/unloading and another for bending.

The second characteristic of product modularity is the minimization of incidental interactions and of coupled interfaces among physical components. The interactions among components usually concern the exchange of energy or the geometric coupling among the physical components. Generally, some of these interactions are fundamental for the correct working of the product, while some others are incidental (e.g., a non desired exchange of heat among components). Moreover, the geometric interfaces among the interacting components can be coupled or decoupled. Interfaces are coupled if a change made to one physical component requires a change to the other interacting physical components. Otherwise, interfaces are decoupled. The product modularity depends on the degree to which the interactions among physical components are non incidental and the geometric interfaces are decoupled.

See also *new product development process; product design process; product architecture*

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## product platforms

*Hilary Bates*

Product proliferation can add complexity to the development process and the organization in general unless it can be based upon a common product platform. Product platforms have generated a lot of academic interest in recent years (Meyer, 1997; Robertson and Ulrich, 1998) and subsequent research has generated many different, some quite product specific, definitions. For our purposes the clearest definition of a product platform is "a set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced" (Meyer, 1997; Meyer and Lehnerd, 1997).

Platforms as an engineering concept have been around for a long time, in many industries. Companies such as Microsoft, Hewlett Packard, and Lotus have made extensive use of product platforms, but perhaps the most recent and widely acknowledged use of the common platform is in vehicle design.

### Platforms and the Auto Industry

Within the automotive industry, there is a perception that it is important to be able to offer vehicles to multiple market segments. Original equipment manufacturers (OEMs) need to have a broad product portfolio, in so far as this does not compromise their image or increase costs to an unsustainable level. This is a tall order for an industry with relatively inflexible and costly production systems and a very complex product. The product platform has been hailed as the way to manage this complexity, by providing a common base from which to develop a family of products capitalizing on common processes, machines, tools, and design effort (*see* PRODUCT FAMILIES). It provides an elegant solution to the difficulties of finding a balance between standardization in production and perceived customization in the marketplace. Most consumers are now aware of the existence of platform vehicles. Volkswagen, for instance, has been in the forefront of developing platform vehicles and possesses some of the most productive vehicle platforms in the market. Probably the best known, and certainly the most productive platform, is the PQ35 platform. This platform underpins the Golf, Bora, Beetle, Audi A3, Audi TT, Skoda Octavia, Seat Toledo, and Seat Leon models. The platform concept has several readily obvious benefits for companies:

- It reduces product development lead times.
- It reduces product development costs and allows cross utilization of production processes and test facilities.

- Using the same components time after time should insure increased product reliability.
- A platform strategy permits companies to serve several niche markets with the same basic product, thereby reducing marketing costs and reducing risk by capitalizing upon reputations gained in other markets.

The vehicle platform started by sharing the floor pan, the frame upon which the vehicle, and the driver, sits. It is, by necessity, the biggest, heavi est, and most expensive pressing in the vehicle and it makes sense to try to use the same pressing across a number of vehicles, thereby gaining significant economies of scale from the produc tion process. In reality, the platform is now a lot more than just one pressing. It is the floor pan and various other groupings of components that can be applied across a family of similar vehicles. It can allow somewhere around 60 percent com monality between vehicles in a product family. For example, in VW a platform is defined as: the floor group (front end, center part, rear end, and the bulkhead), the fuel tank and system, the rear axel (including the braking and the wheels), the cockpit (including the steering column, air con ditioner, on board electrics, pedals, and seat frames), the drive unit (engine and gearbox, engine mounting, cooling system, gear stick, exhaust system, and engine electrics), and front axel system (suspension, steering, brakes, and wheels) (Wilhelm, 1997).

See also *design for manufacture; product architec ture; product modularity; time to market; variety; volume*

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### product process matrix

*Nigel Slack*

The product–process matrix is a model that is used to demonstrate the combination of a prod uct's (or product group's) VOLUME and VAR IETY characteristics, and the nature of the processes that make it. It was originally devised by Hayes and Wheelwright (1979), who saw it as "one way in which the interaction of the product life cycle and process life cycle can be repre sented." In its original form the two dimensions of the matrix were seen in life cycle terms, one of the authors' intentions being to show that pro cesses progress through a predictable life cycle that corresponds to the better known concept of the product life cycle. Since then the model has been used primarily to show the different oper ations needs of products (or product groups) that have different competitive characteristics and to indicate the consequences of failing to match product and process characteristics.

The product–process matrix is an array whose horizontal dimension represents points on the volume–variety continuum from low volume one off products through to high volume, high standardization products. Its vertical di mension represents manufacturing processes, from jobbing through batch and mass to con tinuous (see figure 1).

Product–process combinations can occupy most parts of the matrix, although the two ex treme areas of the bottom left and upper right portions of matrix can be taken as representing combinations which are, for all practical pur poses, unfeasible. It would be difficult to im agine the circumstances under which any operation would wish to manufacture one offs on a continuous basis or high volume standard ized products on a jobbing basis. However, the other parts of the matrix represent the choices open to operations managers.

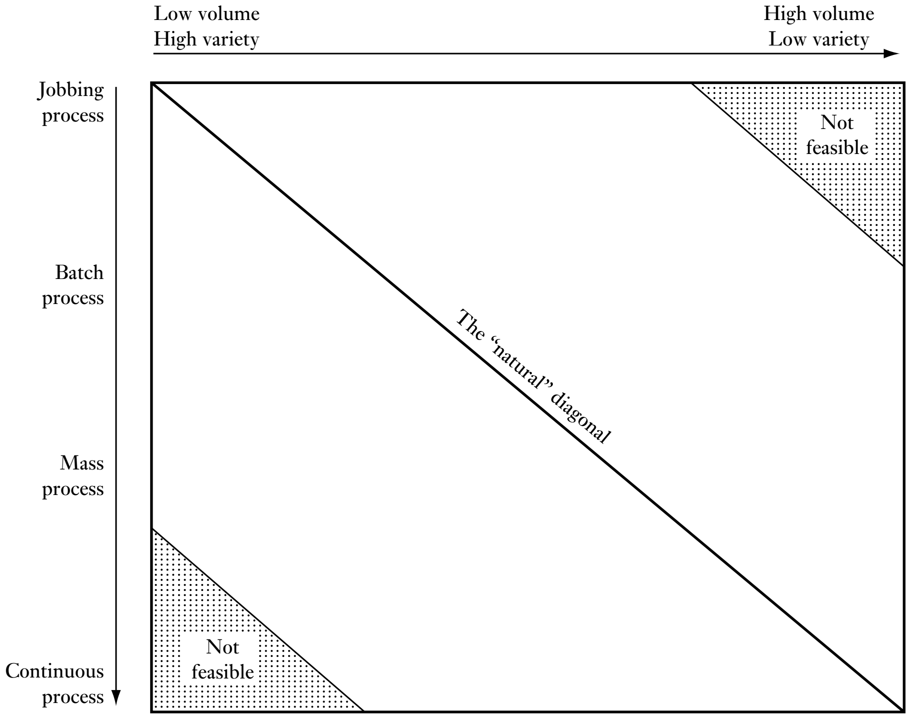


**Figure 1** The product process matrix

Hayes and Wheelwright use the matrix to make three important points. The first is that for all points on the volume–variety continuum there is a corresponding position on the process continuum. This is represented by the "natural" diagonal of the matrix. So companies that supply customized products in low volume will find the flexibility of jobbing process particularly appro priate for their type of business. Companies that supply high volumes of standardized products will see that the low cost production possible with mass or continuous processes enables them to compete effectively. Likewise all points on the volume–variety continuum will corres pond to an appropriate process type.

The second important point made by Hayes and Wheelwright is that companies might move away from the "natural" diagonal, perhaps de liberately in order to achieve some kind of com petitive advantage, or because they "drift" into using inappropriate processes. Either way, there are predictable consequences of moving off the diagonal. Moving from the diagonal in the upper right direction means that the process used to manufacture a product group is more flexible (in terms of being able to cope with a higher variety of product types) than is strictly necessary. The "excess" flexibility might mean that the cost of manufacture is higher than if the manufacturing process was positioned "on the diagonal." Moving from the diagonal toward the bottom left of the matrix results in less flexi bility than would seem to be necessary for the product group's variety. Such an inappropri ately rigid process could incur extra costs, either of lost market opportunities or through the effort and lost capacity needed to change over the process between products.

The third point to be drawn from the matrix is that companies can define their product groups using the model in order to focus their manufac turing resources more effectively. The matrix encourages companies to analyze their products in such a way as to distinguish between the different product groups that require different processes. In this way, it encourages companies to explore alternative product classification boundaries and the consequences of segmenting their manufacturing operations to concentrate on their individual competitive priorities.

Developments of the product–process matrix include substituting other dimensions for the vertical process dimension. For example, a similar argument can be made for a matrix that incorporates scales representing the various dimensions of PROCESS TECHNOLOGY such as the scale (capacity increment) of technology, the degree of automation, or the extent of its integration. The matrix can also be adapted for use with SERVICE OPERATIONS, either by using the same manufacturing process types (which Hayes and Wheelwright, 1984, do) or by substituting SERVICE PROCESSES for the original manufacturing processes.

See also *process types; manufacturing strategy*

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## product service systems

*Michael Lewis*

Various pressures have emerged that have forced manufacturers to consider how they might reduce the resource intensity (i.e., material and energy impact) of their products. For example, when an operation is required to accept product disposal costs (e.g., white goods industry), it has an incentive to reduce the associated costs. Significant end of life product value (e.g., an aircraft engine) creates the opportunity to recover this value by product reclamation activities such as recycling, remanufacturing, or reuse. If product provision becomes a cost rather than a profit (e.g., Chemical Management Services), the provider has a strong incentive to reduce the number of units employed to yield a given quantity of service. These and other factors have led firms (and policy makers) to consider how needs might be fulfilled using innovative systemic combinations of product and service (Goedkoop et al., 1999). In other words, to what extent can key features of the product be "dematerialized" and replaced by less resource intensive service provision, for example, shifting from disposable nappies to nappy cleaning services or from automotive sales to providing personal mobility? From a general economic welfare perspective, "the growth of product–service systems (PSS) could be interpreted as part of a broader economic transition away from standardized and mass production toward flexibility and customization of product offering" (Mont, 2000).

Inevitably there are lots of barriers preventing the effective implementation of many PSS. They necessitate close cooperation between producers and suppliers: "from a buyer's perspective, [PSS] . . . demand closer coordination with, and trust in, suppliers, as well as a more sophisticated understanding of costs than is typical of the conventional seller–buyer relationship," and the practice of whole "life cycle design is a complex process requiring close integration across business functions and specialized decision support tools" (White, Stoughton, and Feng, 1999). Fundamentally, the reorientation of companies toward product–service systems requires a fundamental shift in their corporate culture and market engagement (Mont, 2000).

See also *customer support operations; new product development process; service operations*

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### production flow analysis

*David Bennett*

Production flow analysis (PFA) is a technique that examines product requirements and process grouping simultaneously to allocate tasks and machines to cells in CELL LAYOUT.

It is an approach that examines both product requirements and process grouping simultan eously. In figure 1(a), a manufacturing operation has grouped the components it makes into eight families – for example, the components in family 1 require machines 2 and 5. In this state the matrix does not seem to exhibit any natural groupings. If the order of the rows and columns is changed, however, to move the crosses as close as possible to the diagonal of the matrix, which goes from top left to bottom right, then a clearer pattern emerges. This is illustrated in figure 1(b) and shows that the machines could conveniently be grouped together in three cells, indicated on the diagram as cells A, B, and C. Although this procedure is a particularly useful way to allocate machines to cells, the analysis is rarely totally clean. This is the case here where component family 8 needs processing by machine 3, which has been allocated to cell B.

Generally there are three ways of dealing with this, none of them totally satisfactory:

1 Another machine similar to machine 3 could be purchased and put into cell A. This would clearly solve the problem but requires investing capital in a new machine that might be under utilized.
2 Components in family 8 could be sent to cell B after they have been processed in cell A (or even in the middle of their processing route if necessary). This solution avoids the need to purchase another machine but it conflicts partly with the basic idea of cell layout – to achieve a simplification of a previously com plex flow.
3 If there are several components like this, it might be necessary to devise a special cell for them (usually called a *remainder cell*), which will almost be like a mini process layout. Again this does not conform strictly to the simplicity of pure cell layout and can involve extra capital expenditure. The remainder cell does remove the "inconvenient" com ponents from the rest of the operation, how ever, leaving it with a more ordered and predictable flow.

See also *group working; layout; process layout*

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### productivity

*Roger Schmenner*

Simply stated, productivity measures how ef fectively inputs are converted into outputs. The study of productivity is the search for the best ways to employ resources (labor, equip ment, materials) for production and service pro cesses of all types. Productivity is one of the grand quests of operations management, and, indeed, of economic growth. Only by sustained increases in productivity have national econ omies been able to advance the standards of living for their citizens. Much of the history of

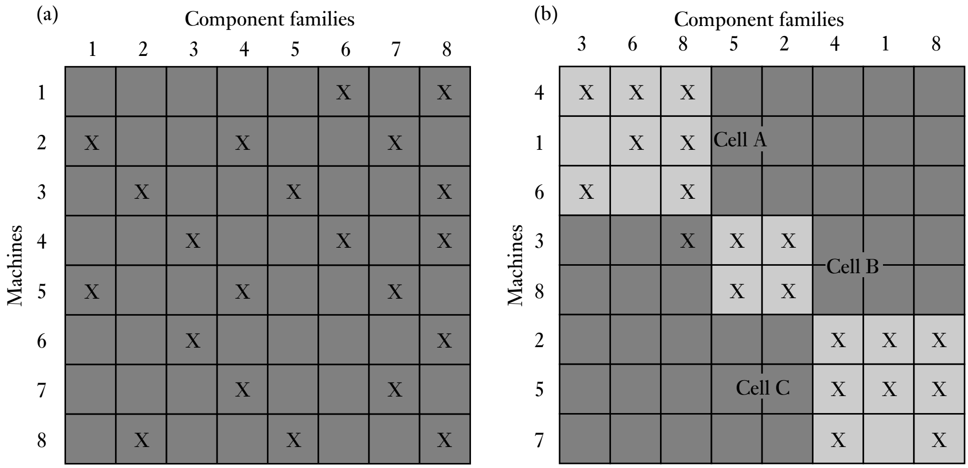


**Figure 1** Using production flow analysis to allocate machines to cells

operations management is a testament to managerial innovation that enabled productivity to rise dramatically.

The measure of productivity is conceptually clear, although in practice it is muddied considerably. In concept, productivity is the ratio of outputs to inputs for an operation (in the micro sense), or for an economy (in the macro sense). A highly productive operation (or economy) uses fewer resources (inputs) of all kinds to produce a given quantity and quality of output, be it a good or a service. In theory, productivity should measure all inputs and all outputs. Inputs are usually varied, and they typically include labor, materials, equipment, and energy. Outputs can be varied as well, encompassing goods and/or services. Theoretically, the most appealing definition is that of "total factor productivity," which essentially examines the value added by the factory (an output measure) per unit of input, where the input is defined as a composite of labor, capital, materials, and energy. This index measure can be defined for specific periods of time and trends identified.

While conceptually clear, such a measure is fraught with ambiguities. Of particular concern are the prices by which both outputs and inputs are valued. And, within the input category, valuing the flow of services from the capital stock is especially challenging. Moreover, once defined, the index has no ready managerial interpretation. It can be analyzed for the source of productivity gain or loss, but its significance to line managers is clouded by the subtleties of its definition. For this reason, the most widely adopted and most easily understood measure of productivity is a "partial factor" productivity measure, namely, labor productivity. Labor productivity is simply the ratio of the value of an output to the value of the direct labor input associated with that output. Labor productivity measures are the most popular measure of a process's productivity, and it is a measure captured by national economies as well.

The first sustained rise in productivity occurred with the industrial revolution, and, in industrialized countries, productivity has continued to rise steadily, although not at a consistently similar rate, due to variations in technological advance and in labor and capital market conditions. Productivity has differed by sector of the economy as well. In general, agriculture has enjoyed a higher rate of productivity advance than any other sector. This, in turn, has implied that the fraction of gross domestic product (GDP) attributable to agriculture is much higher than agricultural employment's fraction of the workforce. Agriculture's enviable productivity has meant that agricultural employment has declined more sharply than any other sector's employment while leaving us better fed than at any other time in history. Manufacturing typically has lagged agriculture in its productivity advance but has far outstripped the service sector of the economy. Thus, the percentage of the workforce in manufacturing has steadily de clined even as goods production has increased.

Productivity growth is widely associated with the acquisition of more and better equipment with which to work, and thus, with an increasing capital to labor ratio. This is the prevailing as sumption of neoclassical economics. Neverthe less, operations management has demonstrated that productivity is a much more subtle concept. The industrial revolution gave birth not only to the invention of many labor saving devices, but also to the factory system whereby labor and equipment came together under one roof with supervision and a central source of power. And, in what historians term the "American system of manufactures," productivity was greatly en hanced by standardized product designs and the introduction of interchangeable parts. Thus, equipment, by itself, has never been the sole driver of productivity gain. Indeed, much of early management practice was devoted to figur ing out how labor should interact with equip ment and power to make goods of better quality and with less waste. Even as the late nineteenth century witnessed an explosion of new machines, mainly for working metal, the SCI ENTIFIC MANAGEMENT movement was inves tigating how best labor itself should be employed to work with the burgeoning quantities of ma chinery of all kinds. On the heels of scientific management came advances in MATERIALS MANAGEMENT and INVENTORY MANAGE MENT and in quality management (e.g., the invention of statistical process control; *see* QUALITY MANAGEMENT SYSTEMS; STATIS TICAL QUALITY TECHNIQUES). Later in the century, the discipline of management science revealed insights into the allocation of resources and in the queuing phenomenon. Both showed how non capital investments can greatly affect the capacity, and thus the productivity, of pro cesses.

In the second half of the twentieth century, Japanese manufacturing practice, particularly the contributions of Taiichi Ohno of Toyota and his Toyota production system, opened the eyes of many western managers to other ways to gain productivity. This philosophy, what has been variously termed JUST IN TIME or LEAN PRODUCTION, has greatly influenced manager ial understanding of productivity. Many of the best performing Japanese factories were not showplaces for new machines but often were havens of older ones to which special equipment had been appended, mainly to "foolproof" the process and assure the production of quality output. The success of Japanese practice has triggered a wealth of study about the fundamen tals of productivity and why some factories or SERVICE OPERATIONS are definitively more productive than others. A rough consensus is emerging from this work about what the operat ing manager should pay particular attention to:

- *Bottlenecks*: An operation's productivity is improved by eliminating or by better man aging its BOTTLENECKS. If a bottleneck cannot be eliminated in some way, say by adding capacity, productivity can be aug mented by maintaining consistent produc tion through it, if need be with long runs and few changeovers. Non bottleneck oper ations do not require long runs and few changeovers. This insight is frequently asso ciated with Eliyahu Goldratt and his "theory of constraints," although it was well known before Goldratt underscored and popular ized its importance.
- *Good methods*: The productivity of labor (i.e., output per worker hour of labor) can be augmented in most instances by applying methods such as those identified by the sci entific management movement, which dates from the time of Taylor, Gantt, and the Gilbreths. In making a scientific study of methods, they discovered a toolbox of im provements that have withstood the tests of time in countless situations. Their work anchors much of INDUSTRIAL ENGINEER ING.
- *Quality*: Productivity can frequently be im proved as quality (i.e., conformance to spe cifications, as valued by customers) is improved and as waste declines, either by changes in product design or by changes in materials or processing. This is a fundamen tal bedrock of the Japanese contribution of just in time. Various techniques of the qual ity movement (e.g., statistical process con trol, fool proofing, Pareto diagrams) can be responsible for these improvements.

Successive "gurus" have been very influential in this quality movement, including such names as DEMING, JURAN, FEIGENBAUM, Ishikawa, Taguchi (*see* TAGUCHI METHODS), Shingo, and CROSBY.

- *Variability*: The greater the variability – either demanded of the process or inherent in the process itself or in the items processed – the less productive the process is. This observation, which derives from queuing theory (*see* QUEUING ANALYSIS) and can easily be verified by simulation, underscores the importance of steady, "level" production plans, the insidiousness of expediting, and the importance of regularity in all of the operations of the factory. The more variable the timing or the nature of the jobs to be done by the process, and the more variable the processing steps themselves or the items processed, the less output there will be from the process.
- *Focus*: Skinner's (1974) influential observation, drawn from his study of factories in a variety of industries, was that those operations which focused on a limited set of tasks were more productive than similar factories seeking to undertake a broader array of tasks (*see* FOCUS).

These observations have been captured and integrated into a recent theory that has been shown to have widespread applicability. The theory of swift, even flow holds that the swifter and more even the flow of materials (or information) through a process, the more productive is that process. Thus, productivity for any process – measured by any means – rises with the speed at which materials (or information) flow through the process, and it falls with increases in the variability associated with the flow, be that variability associated with quality, quantities, or timing. The theory takes the perspective of a molecule in a production process. It looks to throughput time as the relevant measure, from when the molecule is ready to have value added to it until it is a part of the finished product. Throughput time, long favored by the just in time philosophy, is indicative of the waste in a process. The longer the throughput time, the more likely waste of all types bogs down the swift flow of materials.

The theory underscores that it is not necessarily the speed at which value is added to materials (e.g., machine speed or utilization) that is important, because, in most operations, wasteful waiting time far exceeds beneficial value adding time. Instead, it is always adding value that is important so that waiting time can be reduced. Neither is it the capital intensity of a process that determines its labor productivity. According to the theory, capital intensive processes are productive not because capital has replaced labor (as microeconomics asserts), but rather because materials flow swiftly and evenly through them. The investment in capital simply aids speed (e.g., materials handling, production steps themselves) and reduces variation (e.g., better quality), and it is through increased speed and lower variation that capital intensity or any other factor or policy affects productivity. By rejecting a direct connection between capital intensity and productivity, the theory of swift, even flow can explain phenomena that have eluded the conventional view that productivity (e.g., labor productivity) and the capital–labor ratio are formally linked. For example, the labor productivity of the US was greater than that of the UK throughout all of the nineteenth century, despite Britain's greater capital–labor ratio. As mentioned above, economic historians point to the "American system of manufactures," with its standardization and interchangeable parts, as an explanation. Such an explanation that highlights reduced variation in manufacturing fits well with swift, even flow, where it cannot fit with a view that productivity varies directly with capital intensity.

Indeed, the theory of swift, even flow argues that only the swift, even flow of materials (or information) matters to productivity. Other potential explanations – automation, capital intensity, scale, labor efficiency (actual versus standard), machine utilization, or information technology – influence productivity only through their effects on the speed and/or variability of that flow. There are too many examples of situations in which large scale operations became less productive than smaller ones or where new ERP systems did not lead to more productivity or where automation was a net cost to the company (*see* ENTERPRISE RESOURCES PLANNING). Only as these items contribute to reduced throughput times or to reduced vari ation would they be associated with productivity advance.

Swift, even flow is consistent with the break ing of bottlenecks, the improvement of process quality, scientific methods for accomplishing work, level production plans, pull production systems, factory focus, and several other elem ents of modern thinking about managing pro cesses productively. The theory gives managers some paths to follow so that they can improve productivity:

1 If the throughput time is long, the theory suggests hunting for those places in the pro cess where throughput time accumulates. Such places could include areas where in ventory is great or where bottlenecks exist or where materials wait to be worked on. In these cases, management and labor can work to remove waste of one type or another and thus enhance productivity.
2 Evenness can be disrupted by the irregular receipt of orders, either because of irregular timing or because quantities vary consider ably. Evenness can also be disrupted because of the functioning of the process itself: vari ability in the times it takes various tasks to be done, whether by machine or labor, and vari ability in the quality of the process, causing differences in yields. Improving productivity in such instances means, among other things, managing and regularizing the demands on the process, running more level production plans, using pull rather than push mechan isms for moving materials through the fac tory, improving quality, and balancing the steps in the process, perhaps by grouping products or tasks together into families so that cells can be defined (*see* PRODUCT FAMILIES).

Improving productivity in this way, via swift, even flows of materials and information, is nat urally easier said than done. Yet, more and more operations are appreciating the significance of such thinking.

See also *productivity ratios; service productivity*

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## productivity ratios

*Nigel Slack*

The definition of productivity as a ratio is con ceptually straightforward: the total factor prod uctivity (TFP) of an operation can be described by the equation shown in figure 1.

Such ratios only become complex when extended beyond the basic concept or when used to measure the actual productivity of operations. In terms of measurement units, for instance, outputs can be measured in physical terms such as tonnes, cars, or kilowatts, or finan cial terms such as revenue, profit, or added value. Likewise, inputs can be measured in physical terms such as tonnes of material inputs, staff hours worked, or financial terms such as cost of material, cost of labor, or value of assets.

See also *performance measurement; productivity; service productivity*

$$\text{TFP} = \frac{\text{total output of all products and services}}{\text{total resource inputs}}$$

which can be disaggregated to refer to only particular outputs:

$$\text{TFP (for product } X) = \frac{\text{output of product } X}{\text{total resources to make product } X}$$

or particular inputs, when the ratio is called single factor productivity (SFP):

$$\text{SFP (input } Y) = \frac{\text{total output of all products and services}}{\text{input of resource } Y}$$

or both:

$$\text{SFP (output } X, \text{ input } Y) = \frac{\text{output of product } X}{\text{input of resource } Y}$$

**Figure 1** Total factor productivity

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## program management

*Harvey Maylor*

Program management is the process of coordin ating a series of projects and the resources that contribute to them. It has emerged as a new organizational layer of coordination and control as firms have to manage a larger portfolio of, sometimes interrelated, projects.

The role of program management includes the development of the "aggregate project plan." This is the plan that does the following:

- assesses the contribution of each project to the organizational strategy;
- determines using objective criteria what pro jects are to be undertaken;
- ranks the relative importance of the projects being carried out;
- sets the timing of those projects;
- assesses the capability, resource, and logic requirements of each project.

The capabilities or competencies required for the project portfolio should also be considered at this level. There may be key resources or people that are critical to the processes. In add ition, many firms do not consider their key com petencies, trying instead to do everything themselves. This is rarely a successful strategy – particularly where technology is concerned. Where a requirement is outside the firm's set of core competencies, the requirements of exter nal partners or contractors should be discussed (*see* COMPETENCE).

There is an additional consideration for the program manager. The staff involved in a port folio of projects may not be fully aware of the relative importance of the projects on which they are working, or their contribution to overall strategy. Furthermore, attempting to oversee a very large number of projects may result in stress, an issue that may be compounded by confusion regarding prioritization. Program management should insure an appropriately restricted set of activities for any individual.

See also *enterprise project management; project control; project leadership; project management; project stakeholders*

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## project control

*Ralph Levene*

Project control is the set of activities that form a cycle of the planning, monitoring, and controlling of projects. It is generally seen as an important part of PROJECT MANAGEMENT. Control only happens when action is taken subsequent to monitoring to correct deviation from a valid and well established plan. It is vital to effective control to establish baselines and measure progress against them. So attention to the planning process is the foundation of control. The control focus in most projects is on the objectives of time and cost; however, the principles apply to any set of major project deliverables such as materials and specifications. The control stage also involves assessing where the current state of the project is and, more importantly, "where it is going."

### Monitoring

The objective of monitoring is to accumulate progress data, analyze differences from the plan, and forecast what is likely to happen to the project. Monitoring comprises gathering of data, consolidation of the data into reports and graphics, and then analyzing the information to draw conclusions and recommendations for action. Data gathering on a large project is not a trivial task. As much automation as possible should be employed, using techniques such as bar coding and linking constituent systems by means of an integrated database to help to keep down the cost of monitoring. In large projects the cost of management and control can be in the order of 5 percent of the project cost. The frequency of monitoring depends on the overall project duration and what stage the project has reached. At peak progress and often toward completion, monitoring is more crucial and its frequency should increase.

### Change Control

If the difference between plan and actual values is greater than can be accommodated by just minor revisions to the schedule, then the plans and/or budgets have to be changed. At this point, organizations with suitable change control procedures use them to identify the extent of the change and formally incorporate it into the project. The effect of the change on both time and cost should be estimated before agreement, and funding for it should be obtained. This is especially important if the project is a formal contract. Good control is exemplified by making rational decisions and taking corrective action as necessary.

### Communication

The final stage of any control procedure will be to communicate any changes to plans or budgets. This may be part of the review meeting held regularly by the project team, but it is essential that agreed decisions and changes are reported back to the project participants and stakeholders (*see* PROJECT STAKEHOLDERS). Amendments to the project plan should be published and distributed.

### Methods and Procedures

Many organizations have developed standards not only for project control, but for the wider issues of project management, including organization structures and the role of the sponsoring organization. These procedures and methods are as much a part of project management as corresponding QUALITY standards are to the operations of the business. Over the past few years the project management community has seen the development of a number of standard methodologies. Many of these standard methodologies have been assembled by consultants who sell both the method and its implementation. They have their roots in the development of software systems.

See also *project cost management and control*

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## project cost management and control

*Ralph Levene*

The management of cost in PROJECT MANAGEMENT will always be judged by how close the final cost is to the budget. The final budget will not necessarily be the original budget as this may well have been amended by incorporating project changes, both plus and minus. The original budget will relate to the cost estimate approved for the project. The process of estimating starts when the project is conceived and continues at different levels throughout the project. The final part of managing the cost will be to produce a historical report which is essential for improved future estimates. Accurate recording of costs throughout the project is therefore of prime importance. In many projects a large proportion of the project cost is generated from the time that people spend: accurate and timely timesheet recording is therefore essential.

The basic phases of most projects are the same: concept, feasibility, planning, realization, and (organization) implementation. At the end of each of these phases an estimate is produced that increasingly matches the final cost. The concept phase produces a ballpark figure that will only be used to gain agreement to move onto the feasibility phase, when a more detailed preliminary estimate is produced. This should aim to be in the order of 25 percent of the final cost. The planning phase should refine this estimate to the range $\pm 10$ percent to provide the working budget for the major proportion of the project expenditure in its realization and final project delivery.

Data gathered throughout each phase contributes to the definition of the cost estimate and increases its accuracy. Mature and experienced organizations collate costs to an estimating database regularly. Some industries such as petrochemical engineering and construction have the benefit of commercial estimating/cost databases to which they can subscribe. For software development projects there are also parameterized standard models.

Data can also be collected at work package level and future projects can be estimated using a building block approach via the work breakdown structure (*see* WORK BREAKDOWN STRUCTURES).

Once the project is in its realization phase the "estimate" becomes a budget and costs start to incur. The project cost should continue to be "estimated" and take into account actual costs and forecast information. Cost management should always be concerned with the final project cost during this phase and concentrates on trends, evaluating work still to do by looking at the elements that make up the actual costs, for example, work hours (labor), materials, equipment, and overheads. Some of the actual costs come from the organization's financial accounting system. Links between the project cost system and the finance systems have to insure data integrity and timeliness.

Sophisticated cost management systems track actuals not only in cost terms but also in terms of work achievement and its value. Such systems are termed project performance measurement systems (*see* PERFORMANCE MEASUREMENT) and their techniques originate from standards developed by the US military for monitoring complex defense projects. The principle, as with all powerful tools, is simple; the practice is more difficult, especially in relation to measuring the value of work achieved. The cost budget is not just considered as a single value but the planned spend through time is compared throughout the project both to actual expenditure and to the value of work achieved. The key issue in performance measurement systems is the link between time and cost, i.e., the time phasing of costs.

If the cumulative costs of a project are plotted against time, then the shape of the line will be an "s" curve. Many organizations report

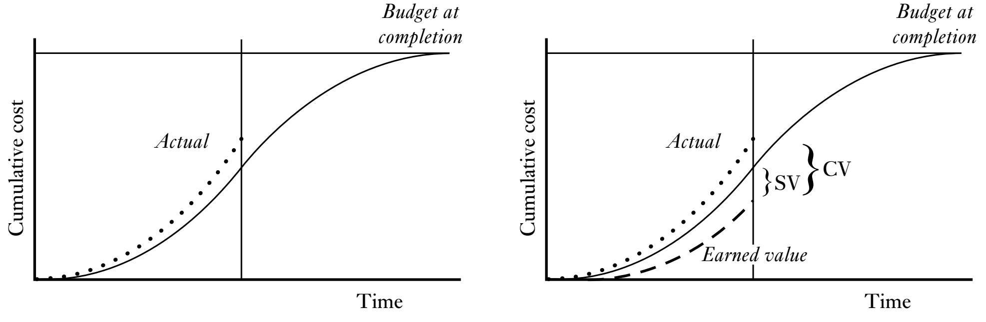


**Figure 1** Examples of project cost management and control graphs

actual expenditure to date against this curve. If the expenditure to date is not the same as the budgeted sum to date, the project has either spent more or less than planned although not necessarily over or underspent. The important issue is to compare how the value of the work done compares to the budget spend and the actual spend. The value of work achieved is commonly called the "earned value." Figure 1 illustrates a typical situation.

From figure 1 it appears that the project has spent more than planned by halfway through its duration. It also shows that it has overspent and that its earned value is less than the budget. Had the earned value line been coincident with the actuals line, the project would have been ahead of schedule.

There is a specific terminology for performance management which relates to the time phasing of the costs. The costs to date are referenced by:

- Actuals = actual cost of work performed (ACWP)
- Budget = budget cost of work scheduled (BCWS)
- Value of work done = budget cost of work performed (BCWP) or the earned value

In addition, useful measures of how close the project is performing to budget are determined by the differences between earned value and actuals, i.e., the cost variance (CV), and earned value and budget, i.e., the schedule variance (SV).

A number of performance indicators are usefully recorded through the project.

- Cost performance index (CPI) = BCWP/ACWP, where $< 1$ represents poor performance.
- Schedule performance index (SPI) = BCWP/BCWS, where $< 1$ represents poor performance.
- To complete performance index (TCPI) = (BAC − BCWP)/(BAC − ACWP), where $< 1$ represents good performance, and BAC is the budget at completion.

The difficulty, in practice, is determining appropriate measures of earned value and putting monitoring systems in place. Objective measures of work accomplishment are easy to establish when physical accomplishment is visible but more difficult in design oriented projects. Measurement can range from subjective assessment to methods for counting physical accomplishment via units of work complete. Appropriate and objective measures of work should be established, taking into account the capability of the organization to regularly monitor progress. Project performance measurement systems are frequently oriented to the project work breakdown structure so that budget, actual, and earned values can be aggregated or "rolled up" through the structure.

See also *project control; project risk management*

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## project leadership

*Ralph Levene*

Within PROJECT MANAGEMENT the role of the project manager is developing in importance in many organizations as the need to work across the organization increases. The traditional skills of many project managers have had to be augmented by financial and strategic skills as organizations orient toward a project style of working and managing change.

An essential ingredient to the success of any project will be the project manager or leader. Although strong leadership may seem to be a vital skill in a task force environment where the authority of the project manager is high, by contrast, in a matrix environment, negotiation skills and diplomacy are more valuable to secure resources. Building the project team and blending them into a cohesive unit is the major challenge in most matrix structures.

As well as completing the project within its time, cost, and quality, all the stakeholders including the team have to be satisfied. This frequently requires addressing competing agendas. Therefore, a project manager must have skills over and above those of a "functional" manager to include those of leadership and motivation in a team environment that often includes temporary resources. The working life of a project manager will be a series of temporary assignments (projects) within which there are many changes in emphasis as each project moves through its life cycle.

Typically, a project manager would need the following knowledge and skills to manage both the project objectives and its team:

- The scope of the project and its objectives.
- The business need for the project.
- The stakeholder requirements and their criteria for success.
- The decision making processes necessary to insure a successful project.
- An appreciation of the systems and procedures required to provide effective project planning and control.
- An ability to present well and communicate.
- Report writing capability.
- Motivational and interpersonal abilities.
- The leadership qualities necessary to create a team and provide the enthusiasm, dedication, and commitment to drive the team to achieve difficult targets.
- Negotiation and diplomatic skills to be able to resolve conflicts that arise at organizational interfaces.
- The management of resources, time schedules, and cash flow.
- The use of output from computerized project control systems.
- An understanding of the supply chain process and how to deal with vendors and suppliers.
- A commitment to quality and safety programs.
- Contracts and the contracting process and how to deal with subcontractors.
- A financial control ability to obtain value for money through sound management.
- Style, in order to engender the trust and confidence of senior management and other stakeholders.

To some extent or other a project manager takes on the following, often competing, roles throughout a project career.

- Director
- Delegator
- Disciplinarian
- Motivator
- Coach and developer (of people)
- Team builder
- Sympathizer
- Decision maker
- Diplomat
- Negotiator
- Manipulator
- Company loyalist

- Rule breaker
- Coordinator
- Resource allocator
- Orator/presenter

An ideal project manager would possess the following attributes to a high level of competence: charisma, charm, assertiveness, inspiration, em pathy, a logical approach, and knowledge.

See also *organization of development; project stakeholders*

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**project management**

*Ralph Levene*

Project management involves the processes of managing change by planning the work, execut ing it, and coordinating the contribution of the people and organizations with an interest in the project. The traditional image of a project is one of physical endeavor such as a major construc tion project or perhaps a new product develop ment. Yet project management is needed when introducing any new entity or making a change that involves moving from one state to another. The view that project management is purely a set of "practical" techniques is belied by its em phasis on teamworking, a perspective that crosses functional boundaries, an orientation to process and logical progression together with strong leadership (*see* PROJECT LEADERSHIP).

THE ORIGINS OF PROJECT MANAGEMENT

Modern project management techniques date from the development of NETWORK TECHNIQUES, which started in the 1950s with their origins in operational research, although prior work on activity planning was pioneered by Henry Gantt at the turn of the century (*see* GANTT CHART). Since then project manage ment has moved to encompass techniques other than those of the planning and scheduling of activities. There have been many developments over the past 50 years to extend project manage ment into detailed methods for the management and control of cost, resources, quality, and per formance.

Project management has developed into a blend of both mechanistic techniques that are designed to help plan and control the project and behavioral or "soft" techniques to help the people processes. In general, the "hard" tech niques are oriented around the planning, monitoring, and control of time, cost, and de liverables; project management software is designed as an aid to these processes. Tech niques for project definition, activity tracking, and work measurement are typified by WORK BREAKDOWN STRUCTURES, network analysis, and cost/performance measurement (*see* PERFORMANCE MEASUREMENT).

Team leadership and building a cohesive team are key elements to insure project success. BEST PRACTICE for the use of any of the planning and control techniques involves a team rather than individual effort; for example, a competent plan ner will involve the key members of the project team in construction of the plan to insure their commitment to it. Team building techniques that involve role identification and team cohe sion are frequently employed to increase the chances of success in major projects.

THE ESSENTIAL CHARACTERISTICS OF A PROJECT

Organizations will carry out two distinct types of project: those that can be classified as develop ment projects and those that relate to organiza tional improvements and changes. The "development" projects are those that arise from the need to create new or improved prod ucts or facilities. The "change" projects will comprise projects that arise from business pro cess improvements to create new ways of working or new organizational forms. These change projects are often classified as BUSINESS

PROCESS REDESIGN (BPR) projects as their size and scope in many cases parallel traditional engineering projects. Whatever the source of the project, it has the same basic characteristics of objectives, organization, and resources to carry it out that distinguish it from a continuous operation.

*Specific objectives and goal.* A project involves people working together to complete a particular end product or specific deliverable (result):

- by a required or specified date;
- to a specified budget;
- to a specific quality or standard of perform ance.

*One off and unique.* Projects are by their nature unique. A similar project may previously have been carried out, perhaps in a different time frame or circumstance, or with a similar technol ogy; however, each project is "one of a kind" in some way.

*Defined duration.* Planned projects have a time frame or finite duration, the end date of which is often related to a business need. This need may well dictate the project time span, influencing when it should start. This in turn will determine when resources are needed to carry out the project.

*Project life cycle.* Projects can de divided into distinct phases. Projects start with a feasib ility phase, then the project is realized and finally implemented into the organization. The project realization phase is frequently expanded into more detailed phases such as design, material purchase, and fabrication. In some in dustries these phases are sequential, whilst in others they are overlapped to a large extent, often in an attempt to shorten the overall project duration (*see* SIMULTANEOUS DEVELOP MENT).

*People issues.* Commitment and backup from senior management is essential to the success of the project. The project manager should have authority over the project team. Frequently the team is made up of people from several different disciplines from different parts of the organiza tion and in international projects from different countries. Priorities between projects have to be clear when the project manager has to negotiate the provision of resources with functional man agers, especially when in competition with other project managers. Leadership as well as sound management becomes all important where the (project) organization structure is a form of matrix. The project organization chosen should strengthen the leadership of the project. A pro ject manager needs to be adaptable to the project circumstance and manage the project in a style appropriate to both the business organization and the type of project (*see* ORGANIZATION OF DEVELOPMENT).

*Managing project change.* The scope of the pro ject can change, often by a large amount, due to changing needs and market conditions. Al though good project management should avoid unnecessary change, project teams must have the ability to assess and control these changes in an effective and timely manner. It is important to keep the client or sponsor advised at all times of potential changes and negotiate their incorpor ation into the project and with an agreed effect on schedule and cost (*see* PROJECT COST MAN AGEMENT AND CONTROL).

## Strategic and Tactical Project Management

The management of the project work within the organization is crucial to turning strategy into reality. Projects can combine into programs of work or project portfolios; managing these be comes an added dimension of project manage ment, using financial appraisal, resource management, and decision making techniques across the organization. These projects in turn may lead to further projects, some of a radical nature, that change the organization to enable it to survive in its "new" environment.

*Strategic project management.* The management of groups of projects is known as either PRO GRAM MANAGEMENT or multiproject manage ment, an area of current development in the discipline. Aspects of program management are concerned with consolidation of the component projects for both directional and planning and control purposes, with a business aim or need as a driver.

There are some examples of organizations that claim to run their entire organizations in a project fashion, this being known as "manage ment by projects."

Program management can be classified into three major areas:

1 Mega projects such as the proposed space station or the Channel Tunnel project.
2 All projects for a single client.
3 Projects grouped together for line of busi ness reasons.

Some organizations would also group organiza tional change projects together.

Program management raises a number of key issues that require careful consideration:

- the decision making processes that link the projects to and within the program for the selection of projects, their prioritization and the allocation of resources;
- who makes decisions about selection or pri oritization within the organization;
- the supporting information systems to help make the decisions;
- an appropriate organizational structure for such a multiproject environment.

*Tactical project management.* In most organiza tions projects are treated as a series of single entities and responsibility for their success is vested in the project manager. The project or ganizations are frequently chosen to fit with the prevailing culture of the company.

The appropriate management style will depend on the skill and competence of the pro ject manager, the type of project – development or change – and its complexity – runner, re peater, or stranger (*see* RUNNERS, REPEATERS, AND STRANGERS). It will also depend on the ability of the organization to employ project management techniques.

See also *enterprise project management; project control; project management bodies of know ledge*

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## project management bodies of knowledge

*Harvey Maylor*

Project management is regarded as unique within the operations management subject area, in having relatively strong professional bodies that publish the combined accepted practice in their areas. These bodies include the Project Management Institute (US based; see http://www.pmi.org), the Association of Project Management (UK; see http://www.apm.org.uk), and the International Project Manage ment Association (European; see http://www.ipma.org).

See also *project management*

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## project risk management

*Ralph Levene*

Risk analysis and management spans the whole project life cycle in PROJECT MANAGEMENT. All projects will have areas of uncertainty; ana lyzing, reducing, and managing it are essential to a well run project. Risks have to be identified, their impact and likelihood assessed, and their reduction or elimination planned and implemented.

Some risks are more obvious than others, for example, technical problems and poor scope identification will almost certainly cause the project to be late and/or over budget. Other risks such as those due to an inexperienced team or bad planning can have a serious effect on the project but can remain hidden.

Causes of risk that can lead to poor performance include poor understanding of scope, lack of estimating methods, novel technology, untrained teams, lack of understanding of client or user needs, bad choice of contractors and suppliers, a lack of project management experience, and uncontrollable events (e.g., weather).

Within each area of risk, specific items that contribute to the risk can be identified, e.g., the design areas are broken down to specific elements of technical risk, and a quantitative value can then be estimated for each to express the degree of risk. In an ideal situation a probability distribution is assigned to each risk element. Then overall project risk is determined by combining the elements into a simulation model (Monte Carlo). Commercially available software packages exist for generalized models that can be formulated and used to explore risks in the cost estimate. Specialist packages that model the network plan and allow distributions to be applied to activity durations are also available (*see* SIMULATION MODELING).

It is essential that the data used are as good as possible. Many organizations neglect to collect actual and comparison data at the end of the project. Probabilistic analysis relies on good data. The PERT method for network analysis (*see* NETWORK TECHNIQUES) was designed to take into account a form of time risk assessment. The method requires three time estimates: "pessimistic" (P), "most likely" (ML), and "optimistic" (O) values for each activity. The PERT duration (PD) for each activity is then calculated as:

$$PD = \frac{(P + 4ML + O)}{6}$$

Reducing the risk is an essential part of the management process. Where parts of the project can be subcontracted, this can also be a strategic decision. The form of the contract, which can range from fully reimbursable to fixed price, relates to the extent of risk that the client is willing to take. In a fixed price contract the contractor assumes all the risk.

The most vulnerable part of a project is often the definition of the scope; a thorough feasibility study can decrease the risk in such cases. Residual risk should be covered by contingency of both time and cost.

See also *failure analysis; project control*

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## project stakeholders

*Harvey Maylor*

The stakeholders in any project are the individuals and groups who have an interest in the project process or outcome. So, for example, the stakeholders in a software development project would include anyone who is a direct user, indirect user, manager of users, support staff member, developer working on other systems that integrate or interact with the one under development, or any other professional potentially affected by the development and/or deployment of the software project.

All projects have stakeholders; complex projects will have many, most of whom will have their own interests that may conflict with other stakeholders. It is the conflicts and potential conflicts between stakeholders that is the focus of attention in stakeholder management. One frequently offered solution to conflict resolution within the stakeholder group is to aim for a high degree of clarity over its rights and responsibilities.

The rights of a stakeholder group may include such points as: expecting project managers to learn and speak in terms they understand; expecting project managers to identify and understand their requirements; receiving ex planations of what is happening in the project; expecting project managers to treat them with respect; expecting to hear ideas and alternatives for requirements; expecting to be presented with opportunities to adjust requirements, to reduce development time, or to reduce development costs; expecting to be given good faith estimates, etc.

The responsibilities of a stakeholder group may include such points as: providing resources (time, money, etc.) to the project team; educat ing project managers about their business; spending the time to provide and clarify require ments to project managers; being specific and precise about requirements; making timely deci sions; respecting a project manager's assessment of cost and feasibility; setting requirement pri orities; reviewing and providing timely feed back; promptly communicating changes to requirements, etc.

A number of benefits of using a stakeholder based approach are cited.

- Project managers can use the opinions of powerful stakeholders to shape the project at an early stage. This makes it more likely that they will support the project, and also can improve the quality of the project.
- Project managers can help to win more re sources – this makes it more likely that pro jects will be successful.
- Project managers can communicate with stakeholders early and frequently, and insure that they fully understand the project and understand potential benefits – this means they can provide active support when neces sary.
- Project managers can anticipate people's re action to the project, and plan the actions that will win support.

The "power–interest" grid is sometimes used to distinguish between different approaches to managing stakeholder groups. This classifies stakeholders by their degree of power to influ ence the project and the degree to which they are affected by the project. The position of a stake holder on the grid indicates the approach to how they may be managed.

- *High power, interested people*: These are the people you must fully engage with and make the greatest efforts to satisfy.
- *High power, less interested people*: Put enough work in with these people to keep them sat isfied, but not so much that they become bored with your message.
- *Low power, interested people*: Keep these people adequately informed, and talk to them to insure that no major issues are arising. These people can often be very help ful with the detail of the project.
- *Low power, less interested people*: Again, monitor these people, but do not bore them with excessive communication.

See also *project leadership; project management*

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## project trade-offs

*Harvey Maylor*

Project trade offs refer to the prioritization of the objectives of a project. This is a vital part of PROJECT MANAGEMENT, as there are two major occasions where it will affect the decisions made. The first is during planning. If a customer indicates that a specification (one aspect of qual ity) for a set of project activities is non negoti able, the resources of time and cost will need to be manipulated around this central objective. Furthermore, it focuses the project on what is really important, as many projects start with unnecessary assumptions regarding what needs to be achieved.

Secondly, it will affect the decisions made during execution. For example, if the most im portant objective for a project is to achieve a particular level of cost performance, where prob lems exist and decisions need to be made, time and quality could be compromised to insure that the cost objective is met. This does look like a poor compromise but it is the reality, particu larly where there are inherent uncertainties in the project. Resources cannot be stretched and stretched to obtain goals that are passing out of sight due to unforeseen problems. It is vital to know in advance what can and cannot be moved should this scenario arise, no matter how un desirable this is in principle. Such a trade off between the main project objectives of time, cost, and quality is illustrated through identify ing the position in what has become know as the "iron triangle." Within this objectives triangle, with time, cost, and quality at its corners, the very middle area is known as "the no go zone." This is where all three project objectives are equally important. This, it is held, results in a conflict between objectives that does not support decision making by project managers.

See also *program management; trade offs*

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## purchasing

*Simon Croom*

In order to carry out their activities, organiza tions require resources. In many sectors the ma jority of the resources employed are in the form of goods and services provided by other organ izations (suppliers). Typically, the amount of expenditure with suppliers is around 50 percent of total income; consequently, purchases form the major costs for organizations in the public and private sectors, manufacturers and service providers alike.

The term purchasing is used to refer to both the *processes* through which those requirements are obtained and the *function* responsible for managing the purchasing process.

- The purchasing process is seen to commence with the identification of a need for re sources, through the determination of the specification for the resource, search for ap propriate source of supply, negotiation of contractual terms, contracting, delivery, and monitoring of the use of the supplied resource.
- The purchasing function has the managerial responsibility for the purchasing process and management of external supply relation ships.

See also *inventory management; location; logistics; material requirements planning; materials manage ment; supply chain management; vertical integra tion*

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## push and pull planning and control

*Nigel Slack*

"Push" and "pull" are terms commonly used in operational planning and control to indicate the direction of the stimulus in the system which causes materials to be moved and activities to be undertaken.

### Push

In a push system of planning and control each work center has responsibility for sending work to the succeeding part of the operation. The work centers "push" out work without considering whether the succeeding work center can make use of it. Activities are scheduled by means of a central system, and completed in line with central instructions, such as a MATERIAL REQUIREMENTS PLANNING system. However, because actual conditions differ from those planned, idle time, inventory, and queues often characterize push systems because, in the short term, activities are not influenced by actual operational conditions.

### Pull

In a pull system of planning and control the pace and specification of what is done is set by the "customer" workstation, who "pulls" work from the preceding (supplier) workstation. The customer acts as the "trigger" for movement. If a request is not passed back from the customer to the supplier, the supplier cannot produce anything or move any materials. A request from a customer not only triggers production at the supplying stage, it will also prompt the supplying stage to request a further delivery from its own suppliers. In this way demand is transmitted back through the stages from the original point of demand by the original customer. Pull systems are less likely to result in inventory buildup.

See also *JIT and MRP/ERP; just in time; kanban; lean production; manufacturing resources planning; planning and control in operations*

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# Q

## quality

*Barrie Dale*

"Quality" is now a familiar term. However, there are a variety of interpretations placed on its use and meaning and there are also multiple definitions. Many people say they know what is meant by quality, claiming typically, "I know it when I see it" (i.e., quality by feel, taste, instinct, and/or smell). This simple statement and the interpretations of quality made by laypeople mask the need to define quality and its attributes in an operational manner. In a linguistic sense, quality originates from the Latin word *qualis*, which means "such as the thing really is." The international definition of quality is "the degree to which a set of inherent characteristics fulfils requirements" (BS EN ISO 9000, 2000).

### Definitions of Quality

There are a number of ways or senses in which quality may be defined, some being broader than others, but they all can be reduced either to meeting requirements and specifications or to satisfying and delighting the customer. These different definitions are now examined.

*Qualitative.* When used in this way, it is usual in a non technical situation. BS EN ISO 9000 (2000) says that "the term 'quality' can be used with adjectives such as poor, good or excellent."

*Quantitative.* The traditional quantitative term that is still used in some situations is acceptable quality level (AQL). This is defined in BS4778 (1991) as: "When a continuing series of lots is considered, a quality level which for the pur poses of sampling inspection is the limit of a satisfactory process." This is when quality is paradoxically defined in terms of non conform ing parts per hundred (i.e., some defined degree of imperfection).

An example of a quantitative measure is to measure processes using sigmas (a sigma is a statistical indication of variation) and parts per million defects. A sigma is essentially a meas uring device that is an indication of how good a product or service is. The higher the sigma value, the lower the number of defects. For example, 3 sigma equals 66,807 defects per million (DPM) opportunities, whilst 6 sigma is 3.4 DPM (these values assume a normal distribution with a process shift of 1.5 sigma). The sigma level is a means of calibrating performance in relation to customer needs (*see* SIX SIGMA).

*Uniformity of a product characteristic or delivery of a service around a normal or target value.* The idea of reducing the variation of part characteristics and process parameters so that they are centered around a target value can be attributed to Tagu chi (1986). He writes that the quality of a prod uct is the (minimum) loss imparted by the product to the society from the time the product is shipped. This is defined by a quadratic loss curve. Among the losses he includes time and money spent by customers, consumers' dissatis faction, warranty costs, repair costs, wasted nat ural resources, loss of reputation, and, ultimately, loss of market share (*see* TAGUCHI METHODS.)

The relationship of design specification and variation of the process can be quantified by a capability index, for example, $C_p$, i.e., a process potential capability index:

$$C_p = \frac{\text{total specification width}}{\text{process variation width}}$$

*Conformance to agreed and fully understood requirements.* This definition is attributed to Crosby (1979). He believes that quality is not comparative and there is no such thing as high quality or low quality, or quality in terms of goodness, feel, excellence, and luxury. A product or service either conforms to requirements or it does not. In other words, quality is an attribute (a characteristic which, by comparison to a standard or reference point, is judged to be correct or incorrect), not a variable (a characteristic which is measurable). He makes the point that the requirements are all the actions required to produce a product and/or deliver a service that meets the customer's expectations, and that it is management's responsibility to insure that adequate requirements are created and specified within the organization (*see* CROSBY).

*Fitness for purpose/use.* This is a standard definition of quality first used by Juran (1988). Juran classifies "fitness for purpose/use" into the categories of quality of design, quality of conformance, abilities, and field service (*see* JURAN). Focusing on fitness for use helps to prevent the over specification of products and services. Over specification can add greatly to costs and tends to militate against a right first time performance. How fit a product or service is for use has obviously to be judged by the purchaser, customer, or user.

*Satisfying customer expectations and understanding their needs and future requirements.* A typical definition that reflects this sentiment is: "The attributes of a product and/or service which, as perceived by the customer, make the product/service attractive to them and give them satisfaction." The focus of the definition is adding value to the product and/or service.

Satisfying customers and creating customer enthusiasm through understanding their needs and future requirements is the crux of TOTAL QUALITY MANAGEMENT (TQM), and all organizations are dependent on having satisfied customers. TQM is all about customer orientation and many company missions are based entirely on satisfying customer perceptions. Customer requirements for quality are becoming stricter and more numerous and there are increasing levels of intolerance of poor quality goods and services and low levels of customer service and care. The customer is the major reason for an organization's existence and customer loyalty and retention is perhaps the only measure of organizational success.

## The Importance of Quality

There are several reasons why quality and its management is an important strategy for world class organizations.

Quality is not negotiable. An order, contract, or customer that is lost on the grounds of nonconforming product and/or service quality is much harder to regain than one lost on price or delivery terms. In a number of cases the customer could be lost forever; in simple terms, the organization has been outsold by the competition.

Quality is all pervasive. There are a number of single focus business initiatives that an organization may deploy to increase profit. However, with the improvements made in mode of operation, reduction in monopolies, government legislation, deregulation, changes in market share, mergers, takeovers, and collaborative joint ventures, there is less distinction between organizations than there was some years ago. TQM is a much broader concept than previous initiatives, encompassing not only product, service, and process improvements but also those relating to costs and PRODUCTIVITY and people involvement and development. It also has the added advantage that it is totally focused on satisfying customer needs.

Quality increases productivity. Cost, productivity, and quality improvements are complementary and not alternative objectives. Managers sometimes say that they do not have the time and resources to insure that product and/or service quality is done right the first time. They go on to argue that if their people concentrate on planning for quality, then they will be losing valuable operational time, and as a consequence output will be lost and costs will rise. Despite this argument, management and their staff will make the time to rework the product and service a second or even a third time, spending considerable time and organizational resources on corrective action and placating customers who have been affected by the nonconformances.

Quality leads to better performance in the marketplace. The Profit Impact of Marketing Strategies (PIMS), conducted under the Stra tegic Planning Institute in Cambridge, Massa chusetts, has a database which contains over 3,000 records of detailed business performance. The database allows a detailed analysis of the parameters that influence business performance. A key PIMS concept is that of relative perceived quality (RPQ); this is the product and service offering as perceived by the customer. PIMS data are often used to model options before adapting a change initiative and to assess how improvements translate into improved profits and enhanced customer loyalty. It has been es tablished that the factors having most leverage on return on investment are RPQ and relative market share and that companies with large market shares are those whose quality is rela tively high, whereas companies with small market shares are those whose quality is rela tively low (see Buzzell and Gale, 1987). Another key finding is that businesses who know and understand customers' priorities for quality im provements can achieve a threefold increase in profitability (Roberts, 1996).

Quality means improved business perform ance. Perhaps the most well known quality/ financial metric is the "Baldrige Index." This is a fictitious stock fund made up of publicly traded US companies that have received the Malcolm Baldrige National Quality Award (MBNQA) from 1991 to 2000. The US Com merce Department's National Institute of Standards and Technology (NIST) invested a hypothetical $1,000 in each of the two whole company winners and the parent companies of 18 subsidiary winners. They also made the same investment in the Standard and Poor's (S&P) 500 at the same time. The investments were tracked from the first business day of the month following the announcement of the award receipts through to December 3, 2001. NIST (2002) reported that the two company winners outperformed the S&P 500 by more than 4.5 to 1, achieving a 512 percent return on investment. The group of whole company award winners plus the parent companies of the sub sidiary winners outperformed the S&P 500 by 3 to 1, a 323 percent return on investment com pared to a 110 percent return for the S&P 500.

The cost of non quality is high. Based on a variety of companies, industries, and situations, the cost of quality (or, to be more precise, the cost of not getting it right the first time) ranges from 5 to 25 percent of an organization's annual sales turnover in manufacturing or annual oper ating costs in services type situations (see Dale and Plunkett, 1999).

Customer is king. In today's markets, cus tomer requirements are becoming increasingly more rigorous and their expectations of the product and/or service in terms of conformance, reliability, dependability, durability, inter changeability, performance, features, appear ance, serviceability, user friendliness, safety, and environment friendly are also increasing. Many superior performing companies talk in terms of being "customer obsessed." At the same time, it is likely that the competition will also be improving and, in addition, new and low cost competitors may emerge in the marketplace; consequently, there is a need for CONTINUOUS IMPROVEMENT in all operations of a business, involving everyone in the company.

Quality is a way of life. Quality is a way of organizational and everyday life. It is a way of doing business, living, and conducting one's personal affairs. In whatever a person does, and in whatever situation, the task(s) must be under taken in a quality conscious way. Quality is driven by a person's own internal mechanisms – "heart and soul" and "personal beliefs." An organization committed to quality needs quality of working life of its people in terms of participation, involvement, and development and quality of its systems, processes, and pro ducts.

## The Evolution of Quality Management

Systems for improving and managing quality have evolved rapidly in recent years. During the last two decades or so simple inspection activities have been replaced or supplemented by quality control, quality assurance has been developed and refined, and now many companies, using a process of continuous and company wide improvement, are working toward TQM. In this progression, four fairly discrete stages can be identified: inspection, quality control, quality assurance, and TQM.

*Inspection.* "Conformity evaluation by observation and judgment accompanied as appropriate by measurement, testing or gauging" (BS EN ISO 9000, 2000). At one time inspection was thought to be the only way of insuring quality. Under a simple inspection based system, one or more characteristics of a product, service, or activity are examined, measured, tested, or assessed and compared with specified requirements to assess conformity against a specification or performance standard. In a manufacturing environment, the system is applied to incoming goods and materials, manufactured components and assemblies at appropriate points in the process, and before passing finished goods into the warehouse. In service, commercial, and public services type situations the system is also applied at key points, sometimes called appraisal points, in the producing and delivery processes.

The inspection activity is, in the main, carried out by dedicated staff employed specifically for the purpose or by self inspection of those responsible for a process. Materials, components, paperwork, forms, products, and goods that do not conform to specification may be scrapped, reworked, modified, or passed on concession. The system is an after the event screening process with no prevention content other than, perhaps, identification of suppliers, operations, or workers who are producing non conforming products/services. There is an emphasis on reactive quick fix corrective actions and the thinking is departmentally based. Simple inspection based systems are usually wholly in house and do not directly involve suppliers or customers in any integrated way.

*Quality control.* "Part of quality management focused on fulfilling quality requirements" (BS EN ISO 9000, 2000). Under a system of quality control one might expect, for example, to find in place detailed product and performance specifications, a paperwork and procedures control system, raw material and intermediate stage product testing and reporting activities, logging of elementary process performance data, and feedback of process information to appropriate personnel and suppliers. With quality control there will have been some development from the basic inspection activity in terms of sophistication of methods and systems, self inspection by approved operators, use of information and the tools and techniques that are employed. Whilst the main mechanism for preventing off specification products and services from being delivered to customers is screening inspection, quality control measures lead to greater process control and reduced incidence of non conformances.

*Quality assurance.* Finding and solving a problem after a non conformance has been created is not an effective route toward eliminating the root cause of a problem. A lasting and continuous improvement in quality can only be achieved by directing organizational efforts toward planning and preventing problems occurring at source. This concept leads to the third stage of quality management development, quality assurance, defined as that "part of quality management focused on providing confidence that quality requirements will be fulfilled" (BS EN ISO 9000, 2000). Examples of additional features acquired when progressing from quality control to quality assurance are, for example, a comprehensive quality management system to increase uniformity and conformity, use of the seven quality control tools (e.g., histogram, check sheet, PARETO ANALYSIS, cause and effect diagram, graphs, control chart, and scatter diagram), statistical process control (SPC), FAILURE MODE AND EFFECT ANALYSIS (FMEA), and the gathering and use of quality costs. The quality systems and practices are likely to have met, as a minimum, the requirements of the BS EN ISO 9001 (2000). Above all, one would expect to see a shift in emphasis from mere detection toward prevention of non conformances. In short, more emphasis is placed on advanced quality planning, training, critical problem solving tasks, improving the design of the product, process, and services, improving control over the process, and involving and motivating people.

*Total quality management.* The fourth and highest level, that of TQM, involves the application of quality management principles to all aspects of the organization, including customers and suppliers and their integration with the key business processes.

Total quality management requires that the principles of quality management be applied in every branch and at every level in the organiza tion, with an emphasis on integration into busi ness practices and a balance between technical, managerial, and people issues. It is a company wide approach to quality, with improvements undertaken on a continuous basis by everyone in the organization. Individual systems, proced ures, and requirements may be no higher than for a quality assurance level of quality management, but they will pervade every person, activity, and function of the organization. TQM will, how ever, require a broadening of outlook and skills and an increase in creative activities from that required at the quality assurance level. The spread of the TQM philosophy would also be expected to be accompanied by greater sophisti cation in the application of tools and techniques, increased emphasis on people, process manage ment, improved training and personal develop ment, and greater efforts to eliminate wastage and non value adding activities. The process will also extend beyond the organization to include partnerships with suppliers and customers and all stakeholders of the business. Activities will be reoriented to focus on the customer, internal and external, with the aim to build partnerships and go beyond satisfying the customer to delighting them. The need to self assess progress toward business excellence is also a key issue.

See also *business excellence model; integrated man agement systems; operations objectives; quality costing; quality management systems; quality teams; quality tools; self assessment models and quality awards; service quality; statistical quality techniques*

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## quality characteristics

*Robert Johnston*

Quality characteristics are the properties of a product or a service, such as size, speed of deliv ery, or friendliness, for example, which are re quired to satisfy the customers. These quality characteristics can be viewed from two perspec tives. Firstly, they are the characteristics that customers expect or require against which they assess the product or service. Secondly, they are the set of measurable variables and/or attributes which comprise the specification that the organ ization uses to assess its production capability and to insure that the specifications are met. Careful market research and clear product offer ings help to insure that these two perspectives are identical.

### Product Quality Characteristics

There are two types of product quality charac teristics, variables, and attributes. Variables are those quality characteristics that can be meas ured on a continuous scale, for example, length or weight. Attributes are those characteristics that are either present or absent, for example, acceptable or not acceptable, within tolerance or out of tolerance. Most operations texts explain in some detail how variables and attributes can be measured using statistical process control (SPC) and statistical quality control (SQC). Few, how ever, provide comprehensive lists of product quality characteristics in the same way as SERVICE QUALITY characteristics.

The most comprehensive list of product quality characteristics is provided by Garvin (1984), who defines the scope of "quality" as comprising performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality. "Performance" comprises the set of "primary operating characteristics": handling, cruising speed, and comfort of a car, for example. "Features" are the secondary characteristics, supporting or enhancing features that supplement the primary characteristics, such as the color of the car's trim and types of accessories. "Reliability" is the chance of a failure occurring. "Conformance" is the degree to which the product meets its specification. "Durability" is a measure of product life. Garvin defined "serviceability" as the speed, courtesy, and competence of repair – the servicing of the product. "Aesthetics" refers to the customer's judgment of the look, sound, or taste of a product. "Perceived quality" recognizes the fact that customers do not possess complete information about a product's attributes and that quality may be, in part, a function of the organization's image and brand names.

Some additional product characteristics have been identified by other authors; for example, the ease of installation and use function, doing what it is supposed to, availability, delivery, and maintainability.

Some authors have argued that reliability is not a quality characteristic but the result or consequence of quality. Others treat reliability separately and argue that it ranks equally with quality in importance in terms of competitive criteria.

## Service Quality Characteristics

Research by Parasuraman, Zeithaml and Berry (1985) provided a list of ten determinants, or characteristics, of service quality: access, communication, COMPETENCE, courtesy, credibility, reliability, responsiveness, security, understanding, and tangibles. In the next phase of their research they found a high degree of correlation between communication, competence, courtesy, credibility, and security, and between access and understanding, and so they created the two broad dimensions of assurance and empathy, i.e., five consolidated dimensions. They then used the five dimensions – tangibles, reliability, responsiveness, assurance, and empathy – as the basis for their service quality measurement instrument, SERVQUAL.

They further reported that, regardless of the service being studied, reliability was the most critical dimension, followed by responsiveness, assurance, and empathy. The tangibles were of least concern to service customers. These dimensions have been much criticized, though they have formed the basis for a considerable amount of research and application in the field of service management. Further research involved some testing of the comprehensiveness of Parasuraman et al.'s service quality determinants. This analysis, although generally supportive of the ten determinants, suggested a refined list of 18 (Johnston, 1995). They are: access, aesthetics, attentiveness/helpfulness, availability, care, cleanliness/tidiness, comfort, commitment, communication, competence, courtesy, flexibility, friendliness, functionality, integrity, reliability, responsiveness, and security. More recently, other characteristics have been suggested that are particularly pertinent to electronic business (*see* E BUSINESS), including speed of downloading and ease of use (e.g., ease of navigation).

## Satisfiers versus Dissatisfiers

Research has shown that the effect of some of the characteristics may be different to others. Johnston (1995) demonstrated that the causes of dissatisfaction are not necessarily the obverse of the causes of satisfaction. It was suggested that the predominantly satisfying service quality characteristics are attentiveness, responsiveness, care, and friendliness and the dissatisfiers are integrity, reliability, responsiveness, availability, and functionality. Responsiveness is identified as a critical determinant of quality as it is a key component in providing satisfaction and the lack of it is a major source of dissatisfaction.

See also *integrated management systems; quality; quality costing; quality management systems; quality teams; quality tools; statistical quality techniques; total quality management; zone of tolerance*

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## quality costing

*Barrie Dale*

Quality costing expresses an organization's quality performance in financial terms. The benefits of quality costs are related to their uses and include the following:

- promote quality as a business parameter;
- help to keep quality aspects of the business under the spotlight;
- enable business decisions about quality to be made in an objective manner;
- help to identify and justify investment in prevention based activities;
- educate staff in the concept of TOTAL QUALITY MANAGEMENT (TQM) as a key business parameter, thereby gaining their commitment and reducing skepticism;
- facilitate PERFORMANCE MEASUREMENT in terms of comparison with other parts of the business, decision making, and motivation;
- identify products, processes, and departments for investigation;
- focus attention on the problems for which compensation has already been built into the system;
- assist in setting cost reduction targets and to measure progress toward targets;
- provide bases for budgeting and eventual cost control.

### Definition of Quality Costs

The importance of definitions to the collection, analysis, and use of quality costs is crucial. Without clear definitions there can be no common understanding or meaningful communication on the topic. Reaching an exact definition of what constitutes quality costs is not straightforward, and there are many gray areas where good operations procedures and practice overlap with quality related activities. Unfortunately, there is no general agreement on a single broad definition of quality costs, and without clear definitions there will be considerable confusion and misunderstanding of what is a quality cost and what is normal business practice.

Some organizations may stretch their definitions to include those costs that have only the most tenuous relationship with quality. This may be to try to create a financial impact. Yet once costs have been accepted as quality related, there may be some difficulty in exerting an influence over the reduction of costs that are independent of quality considerations. If there is a serious doubt, the cost should not be considered as quality related where it is unlikely to be amenable to change by quality management influences. Other suggested criteria to assess whether or not an item is quality related include consideration of whether, if less is spent on it, failure costs will increase, and if more is spent, failure costs will decrease.

### Categorization of Quality Costs

Definitions of the categories and their constituent elements are to be found in most standard quality management texts and detailed guidance is given in specialized publications on the topic. There is widespread use and deep entrenchment of the prevention–appraisal–failure (PAF) categorization of quality costs (Feigenbaum, 1956). There are, however, some general and specific advantages to be gained from the PAF categorization. Among the general advantages are that it may prompt a rational approach to collecting costs, and it can add orderliness and uniformity to the ensuing reports. The specific advantages include its universal acceptance; its conferral of relative desirability of different kinds of expend iture; and, most importantly, its provision of keyword criteria to help to decide whether costs are, in fact, quality related or basic work (e.g., essential activities in producing and sup plying a company's products and/or services). In this way, it helps educate staff in the concept of quality costing and assists with the identifica tion of costs.

However, as TQM has developed, the need to identify and measure quality costs across a wider spectrum of company activities has arisen. The traditional PAF approach is, in some respects, unsuited to the new requirement. Among its limitations are:

- The quality activity elements as defined do not match well with the cost information most commonly available from accounting systems.
- There are many quality related activities in gray areas where it is unclear in which category they belong (this is not detrimental to the process of cost collection, provided the decision making is consistent).
- It is not broad enough to account for many of the activities of non manufacturing areas.
- In practice the categorization is often a post collection exercise done in deference to the received wisdom on the topic.
- The categorization seems to be of interest only to quality assurance personnel.
- It is not an appropriate categorization for the most common uses of quality related cost information.
- To the unwary, because of the distribution of cost elements, it can lead to more focus on the prevention and appraisal components rather than on failure costs.

In these circumstances a broader categorization that measures only the cost of conformance and the cost of non conformances, as in Crosby's (1979) philosophy, is gaining recognition. The principal arguments in its favor are that it can be applied company wide and it focuses attention on the costs of doing things right as well as the costs of getting them wrong. This is considered to be a more positive all round approach that will yield improvements in efficiency. In theory, all costs to the company should be accounted for under such a system. In practice, depart ments identify key result areas and processes against which to measure their performance and costs. Other alternatives of cost categoriza tion include:

- controllable and uncontrollable;
- discretionary and consequential;
- theoretical and actual;
- value adding and non value adding.

### Collection of Quality Costs

The purpose of quality costing should be clari fied at the start as this may influence the strategy of the exercise and will help to avoid difficulties later. If, for example, the main objective is to identify high cost problem areas, approximate costs will suffice. If, on the other hand, the purpose is to set a percentage cost reduction target on the organization's total quality related costs, it will be necessary to identify and measure all the contributing cost elements in order to be sure that costs are reduced and not simply trans ferred elsewhere.

It is necessary to decide how to deal with overheads, since many quality related costs are normally included as part of the overhead, while others are treated as direct costs and attract a proportion of overheads. Failure to clarify this can lead to a distortion of the picture derived from the quality related costs analysis. It is also easy to fall into the trap of double counting. For these and other reasons quality related costs should be made the subject of a memorandum account. Another issue to be decided is how costs are to be allocated to those components, materials, etc. that are scrapped.

There are a number of possible quality cost ing strategies, ranging from measuring and monitoring all quality costs to measuring only failure costs and costing only specific quality improvement projects and activities, and from "one shot" exercises to regular monitoring and reporting. Another aspect that needs to be con sidered is whether to collect and allocate costs on a departmental or business unit basis or across the whole company.

It should not be forgotten that quality costs are already being incurred and the exercise is to identify these "hidden costs" from various budgets and overheads. The objective is to allocate them to a specific cost activity, but some costs, even those directly associated with failure, are not easy to measure.

Quality costing should be a joint exercise. If accountants try to do it alone, they are likely to miss some important details, or even be misled by people with hidden agendas. On the other hand, if quality assurance and/or technical people do it alone, they may fail to discover costs that accountants have tucked away out of sight.

Quality cost information needs to be produced from a company's existing system. It is often recommended that the system used to collect quality costs should be made as automatic as possible with minimum intervention of the cost owners and without significantly increasing paperwork or the burden on the accounts department.

When establishing a quality cost collection procedure for the first time, five points must be kept in mind:

1. The methodology adopted for the collection of costs must be practical and relevant in that it must contribute to the performance of the basic activities of the organization.
2. There is no substitute for a thorough examination of the operating process in the beginning. Modifications to the procedure may be made later, as necessary, with hindsight and as experience of applying the procedure grows.
3. People will readily adopt ready made procedures for purposes for which they were not intended if they appear to fit the situation. Hence the "first off" should be soundly based.
4. Procedures should be user friendly.
5. The management accountant must be involved from the outset.

### Reporting of Quality Costs

In order for matters to become part of a routine costing system, it is first necessary to record the activity or transaction routinely. Once it has been decided which costs are relevant to the organization and which are insignificant, it is important to collect and display all those costs that have been decided upon and also to indicate the existence, by a suitable description, of the relevant costs that cannot yet be quantified. This is important because, firstly, reporting only part of the costs, without some form of qualification, can be very misleading, and, secondly, reporting the existence of unquantified costs keeps them in view of management, helps to insure they are not forgotten, and encourages attempts to find ways of measuring them.

The creation of a quality related cost file, integrated with the existing costing system but perhaps with some additional expenses codes, should not present many problems, although collecting the data will be much more difficult. Some organizations have developed an accounting procedure on quality cost measuring and reporting that is part of the accounting procedure and system. Those quality cost elements that come from within the quality assurance department may be easy to obtain, but those from other departments may present more difficulties, especially if it is suspected that the data may be used in some way to attack them and/or their staff.

A popular view amongst quality management professionals is that quality cost reports should indicate the origin of failure costs by department (e.g., design, production/operations, engineering, purchasing, and marketing), in the hope that this will provoke remedial action. Unfortunately, it may also antagonize departmental managers so that they become uncooperative in providing information for the report. It may even result in the deliberate obscuring of quality performance evidence, resistance to accept the ownership for some costs, and other counterproductive actions.

For maximum impact quality costs should be included in a company's cost reporting system. In the main, reporting on quality costs is a subsection of the general reporting of the quality department activities, so that cost data become entangled and buried with failure data and other quality statistics, and as such lose their impact. For maximum impact quality costs should be included in the overall cost reporting system. It could even be considered as the subject of a separate management report. Unfortunately, the lack of sophistication of quality costs collection and measurement is such that it does not allow quality cost reporting to be carried out in the same detail and to the same standard as, for example, reporting the activities of the operations, marketing, and research and development functions.

Senior managers are like everyone else in wanting easy decisions to make. Having costs, which are the bases of business decisions, tangled up with a considerable amount of technical and quality information makes the data less clear than they could be and often provides an excuse to defer a decision. The problem for senior managers should not be to disentangle and analyze data in order to decide what to do. It should be to decide whether to act, choose which course of action to pursue, insure provision of necessary resources, and, by comparing the quality costs to those budgeted, assess the effectiveness of the planned improvements. Problems, possible solutions, and their resource requirements should be presented in the context of accountability centers that have the necessary authority, if not the resources, to execute the decisions of the senior management team.

See also *integrated management systems; quality; quality management systems; quality team; quality tools; total quality management*

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## quality function deployment

*Nigel Slack*

Quality function deployment (QFD) is a structured procedure used to translate the expressed or perceived needs of customers into specific product or service design characteristics and features, and then to process and operational characteristics. The original technique was developed at Mitsubishi's shipyard in Kobe, Japan, but its adoption by Toyota provided the endorsement that helped insure its widespread use by other companies in other parts of the world. Sometimes referred to as the "voice of the customer," the procedure prioritizes the requirements of the design process (the "whats") and seeks to reconcile them with the attributes embodied in the design "solution" (the "hows"). The central mechanism for doing this is the "what–how" matrix: a data representation framework whose shape gives the procedure its other alternative label, the "house of quality."

The procedure for using the matrix is as follows. In the first "house of quality" matrix, customer requirements form the vertical axis and are matched against the design attributes forming the horizontal axis. The individual elements of the matrix are used to indicate the degree and direction of influence of the main design attributes on customer needs. To do this some form of coding is used, often employing circles and triangles. It is important at this stage to clearly record all assumptions used in judging the nature of these relationships. In effect the process makes explicit what, without QFD, might have remained unexplained in the design process. At the same time, other information is connected concerning both customer requirements and design attributes. First, the correlation between different design attributes is recorded so that the consequence for other attributes of changing one attribute on other attributes is well understood. In addition, specific target values for each design attribute can be defined and, if the product or service is already in use, a competitive assessment comparing the product or service in question with competitors' offerings may be mapped. Similarly, perceived customer rating of each requirement comparing current product or service performance against competitors can also be recorded.

Once the important design attributes have been identified together with an understanding of their current state, these can be transposed to a second matrix to form the "whats" that must be reconciled with the specific design features of the product or service. After a similar analysis, these in turn form the whats of the process matrix, which links design features to the attri butes of the process that will create/deliver the product/service. This in turn can be extended to a final operational matrix to help design the operational control systems (see figure 1).

The main advantages of using a QFD ap proach are:

- it requires designers to be both analytical and explicit in terms of their design objectives (whats) as well as their design solutions (hows) and the relationship between them;
- it helps integrate the various functions and departments commonly associated with design activities in large organizations.

The main disadvantage (commonly cited by practitioners) is the extreme complexity in volved in using QFD in large design projects. The dilemma appears to be that unless the number of factors used in both axes of the matrix is kept under control, then the whole process becomes unmanageable. However, too strict a filtering of design factors and important rela tionships may be overlooked.

See also *design; design for manufacture; design–manufacturing interface; new product de velopment process; product design process; organ ization of development*

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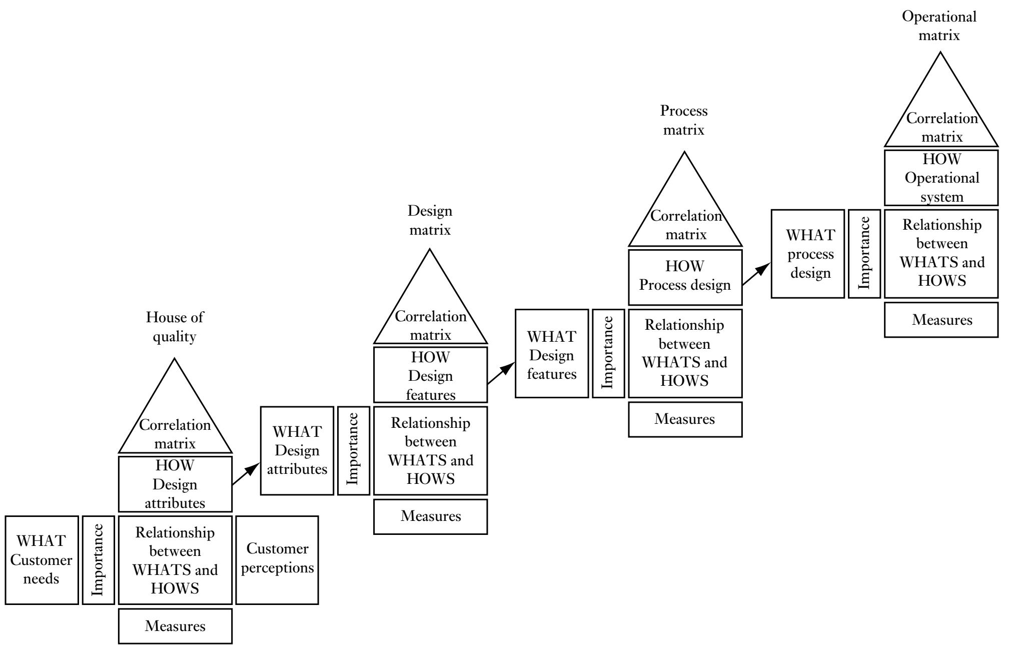


**Figure 1** Translating customer needs through stages in the design process using quality function deployment

Hauser, J. R. and Clausing, D. (1988). The house of quality. *Harvard Business Review*, **66** (3), 63 73.

## quality management systems

*Barrie Dale*

A quality management system is defined in BS EN ISO 9000 (2000) as a "management system to direct and control an organization with regard to quality." The purpose of a quality manage ment system is to establish a framework of refer ence points to insure that every time a process is performed, the same information, methods, skills, and controls are used and applied in a consistent manner. In this way it helps to define clear requirements, communicate policies and procedures, monitors how work is performed, and improves teamwork.

Documentary evidence about the quality management system is fundamental to quality assurance and takes several forms.

- A company quality manual (sometimes called a level 1 document) provides a concise statement of the quality policy and quality management objectives as part of the com pany objectives. ISO 10013 (1995) provides useful guidelines on the development and preparation of quality manuals. A quality manual is defined in BS EN ISO 9000 (2000) as a "document specifying the quality management system of an organization."
- A procedures manual (sometimes referred to as a level 2 document) describes how the system functions, gives the structure and responsibilities for each department/unit, and details the practices to be followed in the organization.
- Work instructions, specifications, methods of performance, and detailed methods for performing work activities for a third level of documents.
- In addition there is often a database contain ing all other reference documents (e.g., forms, standards, drawings, reference infor mation, supplier list, etc.).

The quality management system documentation helps to insure that employees know what they should be doing, along with appropriate means. It also provides evidence to those who wish to assess the system.

The quality management system should define and cover all facets of an organization's operation from identifying and meeting the needs and requirements of customers, design, planning, purchasing, manufacturing, pack aging, storage, delivery, installation, and service, together with all relevant activities carried out within these functions. It deals with organiza tion, responsibilities, procedures, and processes.

A quality management system, if it is to be comprehensive and effective, must cover all these activities and facets and must be developed in relation to the corporate strategy of the com pany. The system developed can be tested against a reference base , i.e., "quality manage ment system standard," and improvements made that describe demonstrable features or conditions that are assessable. An organization's quality management system is usually assessed by the customer (known as second party certifi cation) or by a party that is independent of the customer and the organization (known as third party certification). It is usual to certify that the system conforms to a specific quality manage ment system standard (e.g., ISO 9001) and whether the system is fully implemented and effective. This process is known as certification.

### The ISO 9000 Series of Standards

In simple terms, the objective of the ISO 9000 series is to give purchasers an assurance that the quality of the products and/or services provided by a supplier meets their requirements. The series of standards defines and sets out a defini tive list of features and characteristics that it is considered should be present in an organiza tion's management control system through documented policies, manual, and procedures, which help to insure that quality is built into a process and is achieved. It also insures that an organization has a quality policy, procedures are standardized, defects are monitored, corrective and preventive action systems are in place, and management reviews the system. The aim is systematic quality assurance and control. It is the broad principles of control, in general terms, that are defined in the standards, and not the specific methods by which control can be achieved. This allows the standard to be interpreted and applied in a wide range of situations and environments, and allows each organization to develop its own system and then test it out against the standard. This, however, leads to criticisms of vagueness.

The series of standards can be used in three ways:

1 Provision of guidance to organizations to assist them in developing their quality systems.
2 As a purchasing standard (when specified in contracts).
3 As an assessment standard to be used by both second party and third party organizations.

Functions of the Standards and their Various Parts

The ISO 9000 family of standards consists of four primary standards: ISO 9000, ISO 9001, ISO 9004, and ISO 19011:

- ISO 9000: Quality Management Systems: Fundamentals and Vocabulary
- ISO 9001: Quality Management Systems: Requirements
- ISO 9004: Quality Management Systems: Guidelines for Performance Improvement
- ISO 19011: Guidelines on Quality and Environmental Auditing

The standards have two main functions. The first identifies the aspects to be covered by an organization's quality system and gives guidance in quality management and its application. The second defines in detail the features and characteristics of a quality management system that are considered essential for the purpose of quality assurance in contractual situations.

ISO 9000 outlines the fundamentals of quality management systems and provides the definitions of the key terms used in ISO 9001 and ISO 9004.

ISO 9001 presents quality management system requirements applicable to all organizations' products and services. It is used for demonstrating system compliance to customers, certification of quality management systems, and as the basis for contractual requirements. It requires the following:

- a detailed documentation of quality requirements, processing steps and results;
- implementation of a set of controls to maintain the system;
- compliance to the 22 subelement requirements.

ISO 9004 is a quality management system guidance specification that embraces a holistic approach to performance improvement and customer satisfaction.

ISO 9001 and ISO 9004 employ common vocabulary and structure to facilitate their use and are intended to be used together by organizations wishing to develop their systems beyond the minimum requirements of ISO 9001.

ISO 19001 provides guidance on managing and conducting environmental and quality activities.

The five main elements of ISO 9001 are given below.

*1 Quality management system*
- general requirements: "The organization shall establish, document, implement and maintain a quality management system and continually improve its effectiveness in accordance with the requirements of this international standard" (BS EN ISO 9001, 2000)
- documentation requirements

*2 Management responsibility*
- management commitment
- customer focus
- quality policy
- planning
- responsibility, authority, and communication

*3 Resource management*
- provision of resources
- human resources
- infrastructure
- work environment

*4 Product realization*
- planning of product realization
- customer related processes
- design and development
- purchasing
- production and service provision
- control of monitoring and measuring devices

5 *Measurement, analysis, and improvement*
General: "The organization shall plan and im plement the monitoring, measurement, analysis, and improvement processes needed:

- to demonstrate conformity of the product;
- to insure conformity of the quality manage ment system; and
- to continually improve the effectiveness of the quality management system" (BS EN ISO 9001, 2000)
- monitoring and measurement
- control of non conforming product
- analysis of data
- improvement

The set of requirements outlined in ISO 9001 can be supplemented for specific industries or products by "quality assurance specifications," "quality assurance guidance notes," and "codes of practice," which provide more detail in their form as sector guides.

It is worth mentioning that ISO 14001 (1996), *Environmental Management Systems: Specifica tion with Guidance for Use*, shares many common management principles with the ISO 9000 series. The 2000 revision of ISO 9001 has in sured closer compatibility and synergy with the ISO 14001 and assists in the development of an integrated management system (IMS).

See also *integrated management systems; quality; total quality management*

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## quality teams

*Barrie Dale*

The development of people and their involve ment in improvement activities both individu ally and through teamwork is a key feature in a company's approach to TOTAL QUALITY MANAGEMENT (TQM). A key aspect of this is making full use of the skills and knowledge of all employees to the benefit of the individuals and the organization and to create a group culture. There are a number of different types of teams with different operating characteristics, all of which can act as a vehicle for getting people involved in improvement activities and improv ing organizational performance. Teams can be found everywhere and for almost everything, and most organizations have them. Some teams have a narrow focus, with members coming from one functional area, whereas others are wider and cross functional, dealing with the deep rooted problems between internal customers and suppliers. Each type of team has its set of advantages. There are groups of people already working together, who are also involved in CONTINUOUS IMPROVEMENT activity and form hybrids between two or more types of teams. There is also interaction between differ ent teams, and this form of team activity needs to be effective.

### The Role of Teams in Continuous Improvement

Teams have a number of roles to play as a com ponent in a process of continuous improvement. Teams can:

- aid the commitment of people to the prin ciples of TQM;
- provide an additional means of communica tion between individuals, management, and their direct reports, across functions and with customers and suppliers;

- provide the means and opportunity for people to participate in decision making about how the business operates;
- improve relationships and knowledge, de velop trust, facilitate cooperative activity, and adjust to change;
- help to develop people and encourage lead ership traits;
- build collective responsibility and develop a sense of ownership;
- aid personal development and build confi dence;
- develop problem solving skills;
- facilitate awareness of quality improvement potential, leading to behavior and attitude change;
- help to facilitate a change in management style and culture;
- solve problems;
- imbue a sense of accomplishment;
- improve the adoption of new products to the production line;
- improve morale;
- improve operating effectiveness as people work in a common direction, and through this generate interaction and synergy.

### Types of Teams

In relation to the operating characteristics of any type of teams used in the quality improvement process, the following two points should be noted.

- The key issue is not the name of the team activity, but rather the structure of the team, its operating characteristics, remit, account ability, and ability to resolve problems.
- If management initiates any form of team activity, it has an implicit responsibility to investigate and evaluate all recommenda tions for improvement, implement all feas ible solutions, demonstrate interest in the team's activities, and recognize and celebrate success.

There are a variety of types of teams with differing characteristics in terms of membership, mode of participation, autonomy, problem selec tion, scope of activity, decision making author ity, access to information, problem solving potential, resources, and permanency which can be used in the improvement process. It is important that the right type of team is formed for the project, problem, or activity under con sideration and a working definition of the team is decided upon. The following are amongst the most popular types of teams.

*Project teams.* If senior management identifies the main problems facing the organization, key improvement issues can be developed which are then allocated amongst their membership for consideration as a one off project. The project owner then selects employees to constitute a team that will consider the improvement issue. The owner can either lead the team himself or herself or act as "foster parent," "sponsor," or "guardian angel" to the team. Through partici pation in project teams, managers better under stand the problem solving process and become more sensitive to the problems faced by other types of teams. The senior management project team is one example of this type of team, but there are others. The typical characteristics of such teams are:

- The objective has been defined by senior management.
- The team is led by management.
- It is temporary in nature.
- The project is specific and significant, per haps addressing issues of strategic change, and will have clear deliverables within a set time scale.
- The team is organized in such a way as to insure it employs the appropriate talents, skills, and functions that are suitable in reso lution of the project.
- The scope of activity tends to be cross functional.
- Participation is not usually voluntary – a person is requested by senior management to join the team and this is done on the basis of the individual's expertise for the project being tackled.
- Team meetings tend to be of long rather than of short duration, and they occur on a regular basis.

*Quality circles.* Quality circles (QCs), when op erated in the classic manner, have characteristics that are different from other methods of team work. A QC is a voluntary group of between six to eight employees from the same work area. They meet usually in company time, for one hour every week or fortnight, under the leader ship of their work supervisor, to solve problems relating to improving their work activities and environment.

Their typical characteristics are:

- Membership is voluntary and people can opt out as and when they wish.
- Members are usually drawn from a single department and are doing similar work.
- All members are of equal status.
- They operate within the existing organiza tional structure.
- Members are free to select, from their own work area, the problems and projects that they wish to tackle – these tend to be the ones they have to live with every day; there is little or no interference from management.
- The QC members are trained in the use of the seven basic quality control tools, meeting skills, facilitation, team building, PROJECT MANAGEMENT, and presentation tech niques, etc.
- Appropriate data collection, problem solving skills, and decision making methods are employed by QC members to the project under consideration.
- Meetings are generally of short duration, but a large number are held.
- There is minimum pressure to solve the problem within a set time frame.
- A facilitator is available to assist the QC with the project.
- The solutions are evaluated in terms of their cost effectiveness.
- The findings, solutions, and recommenda tions of the QC are shown to management for comment and approval, usually in a formal presentation.
- The QC implements their recommenda tions, where practicable.
- Once recommendations have been imple mented, the QC monitors the effects of the solution and considers future improvements.
- The QC carries out a critical review of all its activities related to the completed project.

There have been a number of derivatives of QCs resulting in teams operating under a variety of names but with very similar characteristics to QCs.

*Quality improvement teams.* Teams of this type can comprise members of a single department, be cross functional, and include representatives of either or both customers and suppliers. The ob jectives of such teams range across various topics but fall under the general headings of: improve quality, eliminate waste and non value adding activity, and improve PRODUCTIVITY. The characteristics of quality improvement teams are more varied than any other type of team activity but typically include:

- Membership can be voluntary or mandatory and can comprise line workers, staff, or a mixture of both. Some teams involve a com plete range of personnel from different levels in the organizational hierarchy.
- Projects can arise as a result of: a manage ment initiative, a need to undertake some form of corrective action, a high incidence of defects, supplier/customer problems, and an opportunity for improvement. It is usual to agree the project brief with management.
- The team is usually formed to meet a specific objective.
- In the first place, the team leader will have been appointed by management and briefed regarding objectives and time scales.
- The team is more permanent than project teams but less so than QCs. In some cases teams disband after a project, in others they continue.
- Members are usually experienced personnel and well versed in problem solving skills and methods.
- The team is self contained and can take whatever action is required to resolve the problem and improve the process.
- The assistance of a facilitator is sometimes required to provide advice on problem solv ing, use of specific quality management tools and techniques, and keeping the team activ ity on course. In most cases a facilitator is assigned to a number of teams.

See also *group working; integrated management systems; job design; quality; quality costing; qual ity management systems; quality tools*

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## quality tools

*Barrie Dale*

### Tools of Quality Management

To support and develop a process of CONTINUOUS IMPROVEMENT it is necessary for an organization to use a selection of quality management tools and techniques. Most of these tools and techniques are simple, although not all. There are a considerable number of quality management tools and techniques, all with slightly different roles to play in the continuous improvement process. They include:

- summarizing data and organizing its presentation;
- data collection and structuring ideas;
- identifying relationships;
- discovering and understanding a problem;
- implementing actions;
- finding and removing the causes of a problem;
- selecting problems and assisting with the setting of priorities;
- monitoring and maintaining control;
- planning;
- performance measurement and capability assessment.

There are two major factors that need to be considered in selecting quality management tools and techniques. First, the application of any tool and technique in isolation without a quality strategy and long range management vision will only provide short term benefits. Second, no one tool or technique is more important than another; they all have a role to play at some point in the continuous improvement process. A common mistake is to use quality management tools and techniques without thinking through their implications, including issues such as the following.

- What is its fundamental purpose?
- What will it achieve?
- Will it produce benefits if applied on its own?
- Is it right for the company's product, processes, people, and culture?
- How will it facilitate improvement?
- How will it fit in with, complement, or support other techniques, tools, methods, and the quality management system already in place, and any that might be introduced in the future?
- What organizational changes, if any, are necessary to make the most effective use of it?
- What is the best method of introducing and then using it?
- What are the resources, skills, information training, etc. required to introduce it successfully?
- Has the company the management skills and resources, and the commitment, to make it work successfully?
- What are the potential difficulties in using it?
- What are its limitations?

Research by Dale et al. (1998) into the difficulties relating to the use of tools and techniques discovered that the critical success factors relating to the successful use and application of tools and techniques could be grouped into four main categories: (1) data collection; (2) use and application; (3) role in improvement; and (4) organization and infrastructure. Building on this, Dale and McQuater (1998) identified five main influences – experience, management, resources, education, and training – on each of the four success factors.

Some of the basic tools of quality control are as follows.

### Checklists

Checklists are used as prompts and aids to per sonnel. They highlight the key features of a process, equipment, system, product, or service to which attention needs to be given, and to insure that the procedures for an operation, housekeeping, inspection, MAINTENANCE, etc. have been followed. Checklists are also used in audits of both product and systems. They can be a useful aid for quality assurance although their variety, style, and content are extensive.

### Flowcharts

PROCESS MAPPING, in either a structured or unstructured format, is necessary to obtain an in depth understanding of a process. A flow chart is employed to provide a diagrammatic picture, by means of a set of symbols, showing all the steps or stages in a process, project, or sequence of events, and is of considerable assist ance in documenting and describing a process as an aid to examination and improvement. Ana lyzing the data collected on a flowchart can help to uncover irregularities and potential problem points. It is also a useful method for dealing with customer complaints, by establishing the cause of problems in the internal customer chain. In some organizations people are only aware of their own particular aspect of a process, and process mapping helps to facilitate a greater understanding of the whole process. It is essen tial to the development of the internal customer–supplier relationship.

### Checksheets

A checksheet is a sheet or form used to record data. It is a simple recording method for deter mining the occurrence of events such as non conformities, non conforming items, breakdown of machinery and/or associated equipment, and non value adding activity. They are prepared, in advance of the recording of data, by the op eratives and staff being affected by a problem. The data collected on a checksheet provides the factual basis for subsequent analysis and corrective action, using, for example, a PARETO ANALYSIS.

### Tally Charts and Histograms

Tally charts are a descriptive presentation of data and help to identify patterns in the data. They are used with measured data to establish the pattern of variation displayed, prior to the assessment of process capability. A tally chart is regarded as a simple frequency distribution curve. A histogram is a graphical representation of individual measured values in a data set according to the frequency or occurrence. It takes measured data from the tally sheet and displays its distribution using the class intervals or value as a base. The histogram helps to visu alize the distribution of data and there are several forms that should be recognized (i.e., normal, skewed, bimodal, isolated island); in this way, they reveal the amount of variation within a process. There are a number of theoretical models that provide patterns and working tools for various shapes of distribution (*see* STATIS TICAL QUALITY TECHNIQUES).

### Graphs

Graphs, whether presentational or mathemat ical, are used to facilitate understanding and analysis of the collected data, investigate rela tionships between factors, attract attention, in dicate trends, and make the data memorable. There is a wide choice of graphical methods available for different types of application.

### Pareto Analysis

This is a technique employed for prioritizing problems of any time. The analysis highlights the fact that most problems come from a few of the causes and it indicates what problems to solve and in what order. In this way, improve ment efforts are directed at areas and projects that will have the greatest impact.

### Cause-and-Effect Diagrams

These are used to determine and break down the main causes of a given problem. Cause and effect diagrams are often called "fishbone" dia grams because of their skeletal appearance. They are usually employed where there is only one problem and the possible causes are hierarchical in nature. The effect (a specific problem or a quality characteristic/condition) is considered to be the head of the fish, and the potential causes and subcauses of the problem or quality characteristic/condition its bone structure. The diagram illustrates in a clear manner the possible relationships between some identified effect and the causes influencing it. It also assists in helping to uncover the root causes of a problem and in generating improvement ideas.

### Brainstorming

Brainstorming is a method of free expression and is employed when the solutions to problems cannot be deduced logically and/or when cre ative new ideas are required. It is used with a variety of quality management tools and tech niques. Brainstorming works best in groups. It unlocks the creative power of the group through the synergistic effect and in this way stimulates the production of ideas. It can be employed in a structured manner in which the group follows a set of rules, or in an unstructured format that allows anyone in the group to present ideas ran domly as they occur.

### Scatter Diagram

Scatter diagrams are used when examining the possible relationship or association between two variables, characteristics, or factors. They indi cate the relationship as a pattern. For example, one variable may be a process parameter and the other may be some measurable characteristic of the product. As the process parameter is changed (independent variable), it is noted to gether with any measured change in the product variable (dependent variable), and this is repeated until sufficient data have been col lected. The results when plotted on a graph will give a scatter diagram. Variables that are associated will show a linear pattern and those that are unrelated will portray a random pattern.

### Problem-Solving Methodology

The use of tools and techniques should always be employed within a problem solving approach for maximum effectiveness and efficiency. Prob ably the best known problem solving cycle is that of PDCA (plan, do, check, act; *see* PDCA CYCLE). The *plan* aspect of the cycle is usually considered in four stages: (1) define the problem or improvement opportunity and specify object ives; (2) identify the likely causes of the problem; (3) pinpoint the root causes of the problem; and (4) prepare solutions and develop and agree an action plan. The *do* is concerned with imple menting the action plan. *Check* monitors the effectiveness of the actions that have been im plemented, and *act* relates to standardization of the results and transferring the practices to other processes.

See also *integrated management systems; per formance measurement; quality; quality costing; quality management systems; quality teams; Six Sigma; Taguchi methods; total quality management*

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## queuing analysis

*Nigel Slack*

Queuing theory (also called waiting line theory) is a mathematical approach that models random arrival and processing activities in order to pre dict the behavior of queuing systems. It is based on the assumption that in most real processes there is significant variability either in the demand to which the process is expected to respond, or in the time taken for the process to perform its various activities. It is therefore im portant to examine the effects of variability on the performance of such processes.

### Sources of Variability in Processes

There are many reasons why variability occurs in processes. A few of these are listed below.

- The late (or early) arrival of material, infor mation, or customers at a stage within the process.
- The temporary malfunction or breakdown of PROCESS TECHNOLOGY within a stage of the process.
- The necessity for recycling "misprocessed" materials, information, or customers to an earlier stage in the process.
- The misrouting of material, information, or customers within the process that then needs to be redirected.
- Each product or service being processed might be different, e.g., different models of automobile going down the same line.
- Products or services, although essentially the same, might require slightly different treat ment. For instance, in the computer test and repair process, the time of some activities will vary depending on the results of the diagnostic checks.
- With any human activity there are slight variations in the physical coordination and effort on the part of the person performing the task that result in variation in activity times, even of routine activities.

All these sources of variation within a process will interact with one another, but result in two fundamental types of variability.

- Variability in the demand for processing at an individual stage within the process, usu ally expressed in terms of variation in the inter arrival times of units to be processed.
- Variation in the time taken to perform the activities (i.e., process a unit) at each stage.

The effects of variability within a process will depend on whether the movements of units be tween stages, and hence the inter arrival times of units at stages, are synchronized. For example, consider the computer test and repair process described previously. Synchronized flow be tween stages will insure that all movement between the stages happened simultaneously, the interval between each synchronized move ment being set at a level that will allow all stages to have finished their activities irrespective of process variability. Note that under these cir cumstances every stage will experience some degree of idle time, the average idle time at each station being the cycle time minus the aver age activity time at that station. This reduction in the efficiency of the process is only partly a result of its imbalance. The extra lost time is a result of activity time variability.

However, a more common arrangement is to move units between stages in the process as soon as the activities performed by each stage are complete. Here, units move through the process in an unsynchronized manner rather than having to wait for an imposed movement time. This means that each stage may spend less time waiting to move its unit forward, but it does introduce more variation in the demand placed on subsequent stations. Without synchroniza tion, the inter arrival time at each stage will itself be variable.

Queuing analysis is often explained purely in terms of customers being processed through SERVICE OPERATIONS. This is misleading. Al though queuing analysis is particularly import ant in service operations, especially relatively high customer contact operations where custom ers really do wait in line or "queue" for service, the approach is useful in any kind of operation. In the general form of queuing analysis, custom ers arrive according to some probability distri bution and wait to be processed (unless part of the operation is idle); when they have reached the front of the queue, they are processed by one of the parallel "servers," or series of servers (their processing time also being described by a probability distribution), after which they leave the operation.

Queuing or waiting line behavior can be de scribed by a common set of elements.

- *The source of customers*: Sometimes called the calling population, this is the source of supply of customers. The source of custom ers for a queuing system can be either *finite* or *infinite*. A finite source has a known number of possible customers. With a finite source of customers the probability of a cus tomer arriving depends on the number of customers already being serviced. By con trast, an infinite customer source assumes that there are a large number of potential customers so that it is always possible for another customer to arrive no matter how many are being serviced. Most queuing systems that deal with outside markets have infinite, or "close to infinite," customer sources.

- *The arrival rate*: This is the rate at which customers needing to be served arrive at the server or servers. Usually there is variability in their arrival rate.
- *The queue*: Customers waiting to be served form the queue or waiting line itself. If there is relatively little limit on how many custom ers can queue at any time, it can be assumed that, for all practical purposes, an infinite queue is possible. However, there may be a limit to how many customers can be in the queue at any one time.
- *Rejecting*: If the number of customers in a queue is already at the maximum number allowed, then the customer could be rejected by the system.
- *Balking*: When a customer is a human being, he or she may refuse to join the queue and wait for service if it is judged to be too long. In queuing terms, this is called balking.
- *Reneging*: This is similar to balking but here the customer has queued for a certain length of time and then (perhaps being dissatisfied with the rate of progress) leaves the queue.
- *Queue discipline*: This is the set of rules that determine the order in which customers waiting in the queue are served. Most simple queues use a "first come first served" queue discipline.
- *Servers*: A server is the facility that processes the customers in the queue. In any queuing system there may be any number of servers configured in different ways. Many queue systems are complex arrangements of series and parallel connections.

### Balancing Capacity and Demand

The dilemma in managing the capacity of a process with variability is how much capacity (e.g., how many servers) to allocate to a stage in order to avoid unacceptably long queuing times or unacceptably low utilization. Because of the probabilistic arrival and processing times, only rarely will the arrival of customers match the ability of the operation to cope with them. Sometimes, if several customers arrive in quick succession and require longer than average pro cessing times, queues will build up in front of the operation. At other times, when customers arrive less frequently than average and also re quire shorter than average processing times, some of the servers in the system will be idle. So even when the average capacity (processing capability) of the operation matches the average demand (arrival rate) on the system, both queues and idle time will occur.

If the process capacity is set at too low a level, queues will build up to a point where customers become dissatisfied with the time they have to wait, although the utilization level of the servers will be high. If too many servers are in place (i.e., capacity is set at too high a level), the time that customers can expect to wait will not be long but the utilization of the servers will be low. This is why the capacity planning and control problem for this type of operation is often presented as a trade off between customer waiting time and system utilization (*see* TRADE OFFS).

### Customer Perceptions of Queuing

An important aspect of how human customers judge service from a queuing system is how they perceive the time spent queuing. The management of queuing systems usually in volves attempting to manage customers' percep tions and expectations in some way. Maister (1983) proposes a number of principles that influence how customers perceive waiting times:

- Time spent idle is perceived as longer than time spent occupied.
- The wait before a service starts is perceived as more tedious than a wait within the service process.
- Anxiety and/or uncertainty heighten the perception that time spent waiting is long.
- A wait of unknown duration is perceived as more tedious than a wait whose duration is known.
- An unexplained wait is perceived as more tedious than a wait that is explained.
- The higher the value of the service for the customer, the longer the wait that will be tolerated.
- Waiting on one's own is more tedious than waiting in a group (unless you really don't like the others in the group).

### Formulae

A number of formulae have been developed that can predict the steady state behavior of different types of queuing system. Many of these formu lae are extremely complicated, especially for complex queuing systems, and computer pro grams are more widely used to predict the be havior of queuing systems. However, studying queuing formulae can illustrate some useful characteristics of the way queuing systems behave. Moreover, for relatively simple systems, using the formulae (even with some simplifying assumptions) can provide a useful approxima tion to the process performance of queuing systems.

### Notation

There are several different conventions for the notation used for different aspects of queuing system behavior. It is always advisable to check the notation used by different authors before using their formulae.

The following notation is used here:

$t_a$ = average time between arrival
$r_a$ = arrival rate (items per unit time) = $1/t_a$
$c_a$ = coefficient of variation of arrival times
$m$ = number of parallel servers at a station
$t_e$ = mean processing time
$r_e$ = processing rate (items per unit time) = $m/t_e$
$c_e$ = coefficient of variation of process time
$u$ = utilization of station = $r_a/r_e = (r_a t_e/m$
WIP = average work in progress (number of items) in the queue
WIP = expected work in progress (number of items) in the queue
$W_q$ = expected waiting time in the queue
$W$ = expected waiting time in the system (queue time + processing time)

### Types of Queuing System

Conventionally, queuing systems are character ized by four parameters.

- $A$: the distribution of arrival times (or, more properly, inter arrival times, the elapsed times between arrivals);
- $B$: the distribution of process times;
- $m$: the number of servers at each station;
- $b$: the maximum number of items allowed in the system.

The most common distributions used to de scribe $A$ or $B$ are:

1 the exponential (or Markovian) distribution, denoted by $M$; or
2 the general (e.g., normal) distribution, denoted by $G$.

So, for example, an $M/G/1/5$ queuing system would indicate a system with exponen tially distributed arrivals, process times de scribed by a general distribution such as a normal distribution, with one server and a max imum number of items allowed in the system of 5. This type of notation is called Kendall's Notation.

Queuing analysis can help us investigate any type of queuing system, but in order to simplify the mathematics we shall here deal only with the two most common situations, namely,

- $M/M/m$: the exponential arrival and pro cessing times with $m$ servers and no max imum limit to the queue.
- $G/G/m$: general arrival and processing dis tributions with $m$ servers and no limit to the queue.

Some formulae are stated below. For derivations see Hopp and Spearman (2001).

### For $M/M/1$ Queuing Systems

$$\mathrm{WIP}_q = \frac{\mathrm{u}}{(1Gu)} \times t_e \times \frac{\mathrm{u}}{t_e}$$
$$= \frac{\mathrm{u}^2}{(1Gu)}$$

### For $M/M/m$ Systems

$$W_q = \frac{u^{\sqrt{2(m+1)}} - 1}{m(1\mathrm{G}u)} t_e$$

### For $G/G/1$ Systems

The assumption of exponential arrival and pro cessing times is convenient as far as the math ematical derivation of various formulae is concerned. However, in practice, process times in particular are rarely truly exponential. This is why it is important to have an idea of how $G/G/1$ and $G/G/M$ queues behave. However, exact mathematical relationships are not possible with such distributions. Therefore, some kind of approximation is needed. The one here is in common use, and although it is not always accurate, it is useful for practical purposes.

For $G/G/1$ systems the formula for waiting time in the queue is as follows.

$$W_q = \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u}{(1Gu)}\right)t_e$$

There are two points to make about this equation. The first is that it is exactly the same as the equivalent equation for an $M/M/1$ system but with a factor to take account of the variability of the arrival and process times. The second is that this formula is sometimes known as the *VUT* formula because it describes the waiting time in a queue as a function of

- *V*: the variability in the queuing system;
- *U*: the utilization of the queuing system (i.e., demand versus capacity); and
- *T*: the processing times at the station.

This presentation stresses the intuitive conclusion that queuing time will increase as variability, utilization, or processing time increase.

### For $G/G/m$ Systems

The same modification applies to queuing systems using general equations and *m* servers. The formula for waiting time in the queue is now as follows.

$$W_q = \left(\frac{c_a^2 + c_e^2}{2}\right)\left(\frac{u^{\sqrt{(2m+1)}\;\;1}}{m(1Gu)}\right)t_e$$

See also *design; simulation modeling; transformation model*

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# R

**reliability-centered maintenance**

*Michael Shulver*

Reliability centered maintenance (RCM) is a form of PREVENTIVE MAINTENANCE (PM) which, rather than focusing on the reliability of individual pieces of equipment, instead seeks to preserve the overall function of an operating system. In general, the concept of RCM is applicable in large and complex systems such as large passenger aircraft, military aircraft, oil refineries, and power stations. Although one of the prime objectives of RCM is to reduce the total costs associated with system failure and downtime, evaluating the returns from an RCM program solely by measuring its impact on costs hides many other less tangible benefits. Typically, these additional benefits fall into the following areas:

- improved system availability;
- optimizing spare parts inventory;
- identification of component failure significance;
- identification of hidden failure modes;
- discovery of significant, and previously unknown, failure scenarios;
- providing a training opportunity for system engineers and operations personnel;
- identification of components where an increase in maintenance task periodicity or life can reduce costs;
- identification of candidate areas for design enhancements;
- providing a detailed review, and improvement where necessary, of plant documentation.

The RCM approach first emerged in the late 1960s and early 1970s when the increasing complexity of systems (and consequent increasing size of the PM task) resulted in a rethink of maintenance policy by manufacturers and operators of large passenger aircraft. Pioneering work on the subject was done by United Airlines in the 1970s to support the development and licensing of the Boeing 747. The principles that define and characterize RCM are (1) a focus on the preservation of system function; (2) the identification of specific failure modes to define loss of function or functional failure; (3) the prioritization of the importance of the failure modes, because not all functions or functional failures are equal; and (4) the identification of effective and applicable PM tasks for the appropriate failure modes. (Applicable means that the task will prevent, mitigate, detect the onset of, or discover, the failure mode. Effective means that among competing candidates the selected PM task is the most cost effective option.) These principles, in turn, are implemented in a seven step systems analysis process:

1. system selection and information collection;
2. system boundary definition;
3. system description;
4. functions and functional failures;
5. FAILURE MODE AND EFFECT ANALYSIS;
6. logic (decision) tree analysis (including a criticality classification of component failure);
7. maintenance task selection.

CONDITION BASED MAINTENANCE (CBM) is often confused with RCM. However, after "the identification of effective and applicable PM tasks for the appropriate failure modes," on condition maintenance might be one of a number of resulting policy/action decisions at the component level, i.e., as a result of imple menting the RCM approach a picture of the deterioration characteristics of components will emerge. These characteristics can then be used to make decisions on the desirability of monitor ing the component, the techniques to be used, and their periodicity. In practice RCM will usu ally result in a combination of policies at the system component level. These include simple inspection procedures (low cost procedures designed to detect minor problems), condition based monitoring of system components, trend monitoring (where little is known about system components' deterioration characteristics, ex perience is accumulated in the monitoring pro cess), operate to failure policies, and opportunity maintenance policies.

See also *failure analysis; maintenance; total productive maintenance*

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## risk and operations

*Michael Lewis*

Day to day processing in various types of manu facturing and service operation requires man agers to cope with hazards for their employees, customers, the environment, and so on. More over, for many operations, significant external scrutiny (in areas such as health and safety, JOB DESIGN, training, product/service design, SUPPLY CHAIN MANAGEMENT, etc.) is now accepted as part of the operations management (OM) context. Correspondingly, operational risk has immediate theoretical and practical sig nificance. The concept is underresearched (Lewis, 2003), of inter disciplinary academic interest, and, for many firms, legal and ethical imperatives mean that operational risk issues (even if not labeled as such) occupy a significant amount of managerial time.

### Defining Operational Risk

OM is, at least implicitly, focused on a range of uncertainty management issues: from reducing variability in production processes to the cre ation of flexible manufacturing technology in order to respond to market or process uncertain ties (Kamrad and Lele, 1998). Likewise there are clear similarities between QUALITY and risk management. Several practical risk frameworks (e.g., FAILURE MODE AND EFFECTS ANALY SIS) are also found in comprehensive surveys of quality techniques and underlying analytical structures share many common features. As a result, a working definition of operations related risk can be adapted from a generic risk definition such as "the potential for realizing unwanted negative consequences from causal events" (Rowe, 1977: 23). In other words, causative events can be viewed as inputs to operational risk processes, which sometimes transform into unwanted negative consequences. Equally, op erational controls (e.g., quality management techniques) seek to intervene at each stage of the transformation process.

- *Causal events.* When classifying the roots of "industrial crises," Shrivistava et al. (1988: 290) identify human (Reason, 1990), organ izational (Turner, 1978), and technological (Perrow, 1984) causal factors. Whilst provid ing a useful starting point, the notion of a discrete causal event offers only a very ap proximate summary of the origins of "real" operational failure. The notion of a time limited causal event is problematic because it does not capture how incidents are inter related and "propagate" over time. Certain events are not the direct cause of specific operational incidents, but without their having taken place, subsequent events could/would not have occurred in the same manner. Indeed, by definition, many oper ations related events will be repetitive or even continuous over time. This implies that operational risk needs to formally in corporate the temporal "pathology" of an operational failure, incorporating repetitive micro events that only cumulatively generate negative consequences (e.g., repetitive strain injuries). It is interesting to speculate that such a mechanism may be inversely analogous to the mechanisms of CONTINUOUS IMPROVEMENT/*kaizen*, whereby incremental improvements lead to more capability development over time.

- *Negative consequences.* It may be possible to partially define operational risks as those caused by events "generated" by operations activities, but negative consequences can travel far beyond functional (and organizational) boundaries. Just as a number of quality authors have argued that the relationship between quality and cost is problematic – for instance, the Taguchi concept that "any" deviation from a specific target value causes increasing loss (defined by a squared functional form, $y = x^2$) – so the increased and increasing negative consequences ascribed to operational events deviation derive from the argument that broader losses (i.e., to customers, other stakeholders, the environment, etc.) also need to be considered.

## Controlling Operational Risk

Any comprehensive risk control classification considers "ex ante," "in process," and "ex post" mechanisms.

*Ex ante mechanisms.* There are many potential controls for preventing operational risks. Inspection/auditing is a highly visible but expensive (and often ineffective) "direct" mechanism for reducing uncertainty by increasing knowledge (about resources, processes, markets, etc.): for example, when a news story emerged accusing a supplier to ethical retailer the Body Shop of using animal testing, the firm was forced to introduce a detailed and expensive auditing method to try to prove that there was no unethical behavior in its entire supply chain. "Indirect" prevention strategies often change specific operating parameters: a building surveying service, for instance, might seek to replace the people in its drafting operations with new scanning and printing technology in order to improve process consistency, remove common errors, and hence minimize pure operational risks (Hollman and Forrest, 1991). More strategically, some operational risks can be avoided (ex ante control) by deferring certain decisions. For instance, acquiring a five year option (the right but not the obligation) on an innovative technology license is valuable because it offers the opportunity to defer further operational costs until more information (market potential, prices, etc.) is available (Amram and Kulatilaka, 1999).

*In process mechanisms.* Secondly, there are in process or mitigation strategies. Not all events can or need to be avoided, and in such circumstances an operation seeks to isolate them from their negative consequences. Interestingly, many "traditional" quality practices aimed to mitigate rather than prevent pure risks. In PURCHASING, for instance, goods inward inspections and multiple suppliers for the same subcomponent were justified on the grounds that, given the possibility of supplier failure events (industrial action, fire, poor quality production, financial difficulties, etc.), these techniques could minimize the negative consequences. For more strategic operational risks it is instructive to consider the example of a multinational consumer goods firm wanting to invest in Eastern European and Central Asian markets. Their Russian subsidiaries could either source all their products from factories in France and Germany, or they could establish local manufacturing facilities. When considering different options, the firm had to consider its operating exposure to a devaluation of the currency. Such devaluation would leave the cost structure of the "foreign supply" option at a serious disadvantage without any real option to increase prices (Huchezermeier and Cohen, 1996). A generic approach to the mitigation of operating exposure (Kogut and Kulatilaka, 1994), whilst continuing to embrace speculative opportunities, necessitates the creation of a portfolio of operational "switching" options. These might include developing alternative suppliers in different currency zones, building up excess/flexible capacity in a global network, creating differentiated products that are less price sensitive, and so on.

*Ex ante mechanisms.* Finally, there are ex post or recovery strategies. In the absence of, or after the failure of, prevention and mitigation strategies, an operation acknowledges and attempts to manage any eventual negative consequences. Recovery strategies comprise a wide range of activities, including the SERVICE QUALITY techniques necessary to minimize an individual customer's dissatisfaction (Hart, Heskett, and Sasser, 1990). This might include apologizing, refunding monies, reworking a product or ser vice, providing an alternative, and providing compensation. At the same time, operations may also have to face a major crisis necessitating a complete product recall or abandonment of service (Augustine, 1995).

See also *failure in operations; fault tree analysis*

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## robotics

*John Bessant*

A robot is an automatic position controlled re programmable manipulator that is capable of handling materials, parts, tools, or specialized devices through variable programmed motions. It often has the appearance of one or several arms ending in a wrist. Its control unit uses a memor izing device and sometimes it can use sensing and adaptation appliances that take account of the environment and circumstances. These mul tipurpose machines are generally designed to carry out repetitive functions and can be adapted to other functions without permanent alterna tion of the equipment.

The term "robot" was first coined by a Czech playwright, Carel Capek, in his play *Rosum's Universal Robots*, where it was used to refer to automatons capable of carrying out a range of human activities. Experiments aimed at develop ing such devices for industrial applications date back at least to World War II, but it was not until the emergence of IT that suitable control systems began to appear to facilitate practical robotics.

Early robots were mainly used for repetitive tasks such as diecasting and found most applica tions in the large car manufacturing plants. The Norwegian firm Tralfa developed the first tool handling robot for paint spraying in 1966 and welding applications emerged in the late 1960s; in each case, the main applications were in high volume series. In the much bigger application area of high flexibility tasks where reprogram mability would be important, it was not until ASEA in Sweden developed a robot using elec tric rather than hydraulic drives in 1973 that this field began to open up. This design offered greater precision of control over movements, and the emergence of microprocessor control during the following years opened up possibil ities in smaller batch work, especially in assem bly areas. Unimation's PUMA (programmable universal machine for assembly) was originally developed for General Motors in 1978 but found widespread application in a variety of tasks.

Reduced costs and more sophisticated IT in frastructures have enabled robots to diffuse widely, especially in their simpler form: for in stance, reprogrammable manipulators and "pick and place" devices are now commonplace in manufacturing and assembly operations. Hugely sophisticated applications are still less common, in part because of enduring technological prob lems (vision, manipulation of non rigid mater ials, etc.) and partly because the costs of robots are still high relative to manual labor (especially in a globalized economy) for manipulative tasks. Thus most applications are in locations where labor costs are high or where tasks are too dan gerous for human intervention.

See also *advanced manufacturing technology; com puter integrated manufacturing; flexible manufac turing system; process technology*

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## runners, repeaters, and strangers

*Nigel Slack*

Runners, repeaters, and strangers is a planning and control classification based on the frequency with which a manufacturing operation is called upon to make a product or deliver a service. It is related to the central concepts of VOLUME and VARIETY and the corresponding assumptions about how different degrees of each dimension imply different methods of treating product groups.

- Runners are products or parts that are pro duced frequently, such as every week.
- Repeaters are products or parts that, al though being produced regularly, are manu factured at longer time intervals.
- Strangers are products or parts that are pro duced at long, irregular, and possibly unpre dictable intervals.

While the exact time scale of production inter vals and boundaries between the three categories is almost certain to vary between different in dustries, the principle of distinguishing bet ween different product groups in this manner has precedent. It is well accepted that the volume and variety characteristics of products will influence the design planning and control of the processes that are required to manufacture them.

See also *planning and control in operations; process types; service processes*

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# S

## safety stocks in MRP

*Peter Burcher*

Safety stocks in MRP systems are held, as in any manufacturing system, to cater for uncertainty. In a MATERIAL REQUIREMENTS PLANNING (MRP) system the major cause of uncertainty, that of the future usage of the item, has been mainly eliminated since items should be produced to meet a plan: the MASTER PRODUCTION SCHEDULE. Therefore, overall, safety stocks in an MRP system should be significantly lower than in a system using classic inventory control policies (*see* INVENTORY MANAGEMENT).

However, safety stocks may still be needed because of uncertainties in supply both in terms of the variation of actual lead times and the variation of quantities supplied caused by process failures, inspection rejects, and material shortages. There may also be changes of demand caused by short term (emergency) changes to the master schedule and unexpected demands for items for spares.

The statistical techniques of establishing safety stocks used in classic INVENTORY CONTROL SYSTEMS are not directly transferable to the MRP environment. Alternative methods have therefore been developed for application to MRP which fall into three main categories: fixed quantity safety stocks, safety times, and percentage increases in requirements.

### Fixed-Quantity Safety Stocks

This method triggers a net requirement whenever the projected stock on hand reaches a safety stock level rather than zero. The calculation of the size of the fixed quantity safety stock should be related to the cause of the unexpected usage or failure of supply during the lead time. For example, if an unplanned demand is primarily as a result of non forecast spares demand for the item, then a historical analysis of this variation may lead toward the setting of a safety stock level that gives a satisfactory service level.

### Safety Time or Safety Lead Time

This approach for setting safety margins is essentially planning to make items available earlier than they are required. The introduction of safety time is straightforward in that the net requirements are offset by the lead time and the safety time to produce planned orders. It is important to realize that the introduction of safety time does not have the same effect as increasing the lead time, since the due dates on planned orders will be a lead time after the planned order release date; i.e., there will be a safety time before the actual net requirement due date. The choice of the length of the safety time could be related to the variability of the manufacturing or procurement lead time of the item being considered. However, since other factors may influence the use of the safety stock generated by the use of safety time, a safety time set taking account of the item value and the penalty of running out, and then subsequent adjustment based on the monitoring of the usage of the safety stock, may be satisfactory.

### Percentage Increase in Requirements

This method is particularly suitable for dealing with the variations in supply caused by scrap or process yield losses and is often implemented as "scrap factors" or "shrinkage factors." This type of safety margin is introduced by increasing the net requirements by a factor to produce planned orders. The size of the percentage increase in requirement should be directly related to the actual scrap or process yield loss for which it is supposed to be compensating. If this margin is to be used as a buffer against other variations, then an arbitrary setting may be made and sub sequently modified, based on the feedback of the actual use of the safety stock generated.

Safety stocks of finished products to provide a predetermined customer service level should be set by analyzing the operation of the sales fore cast and translating the resulting requirements into a master production schedule for the fin ished products.

See also *manufacturing resources planning; netting process in MRP*

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### sandcone model of improvement

*Kasra Ferdows*

The sandcone model of improvement is an ana logy that seeks to explain how assigning prior ities to OPERATIONS OBJECTIVES may result in lasting improvements in performance.

Based on an interpretation of data from the Global Manufacturing Futures Survey to which they contribute, Ferdows and De Meyer (1990) suggest that lasting improvements in perform ance depend on effort being applied in creating a particular sequence of capabilities and that these capabilities should be considered as cumulative developments, building on each other. The model is called the sandcone model because the sand is analogous to the management effort and resources. To build a stable sandcone the base must be continually widened to support increas ing height.

The first "layer" of improvement, and a pre condition to all lasting improvement, is effort applied to *quality* performance. Only when the operation has reached a minimally acceptable level in quality should it then tackle issues of internal *dependability*. But moving on to include dependability in the improvement process should not stop the operation making further improvements in quality. Indeed, improvement in dependability will actually require further improvement in quality. Once a critical level of dependability is reached, enough to provide some stability in the operation, the next stage is to turn attention to the *speed* at which materials flow through the operation, but again, only while continuing to improve quality and dependability further. Now, according to the sandcone model, is the best time for *cost* to be tackled head on. Thus cost reductions are seen as a consequence of other improvements.

See also *breakthrough improvement; business ex cellence model; continuous improvement; cost; delivery dependability; flexibility; quality; time based performance*

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### scheduling

*Nigel Slack*

Scheduling is the process of formulating a plan to indicate which jobs will be completed within a given time scale. The scheduling activity is one of the most complex tasks in operations manage ment. Schedulers must deal with several differ ent types of resource, most with different constraints, simultaneously. Also, the number of possible schedules increases rapidly as the number of activities and processes increases. For example, if one machine has $n$ jobs to process, there are $n!$ different ways of scheduling the jobs through a single process. With $m$ machines and $n$ jobs there are $(n!)^m$ possible schedules. So, with realistic values of many tens or hundreds of jobs and machines, the scheduling task rapidly becomes very complicated. Within the very large number of schedules there are many acceptable options as to which are appropriate routes and sequences for any set of jobs. Even where a product is manufactured repeatedly, there may be a number of different routes which that product could take. However, most of the schedules that are possible in theory will not be workable in practice and these can be rapidly eliminated.

The scheduling task may also have to be repeated on a frequent basis to allow for market variations and product mix changes. Even minor product mix changes may cause the capacity constraints within the facility to change over a comparatively short period of time, with BOTTLENECKS moving between machines.

The scheduling activity has three conflicting objectives. First, scheduling attempts to meet due dates (the time when the job is due to be completed). Second, it attempts to minimize the time the job spends in the operation, i.e., minimize the throughput time (*see* TIME BASED PERFORMANCE). Third, it attempts to maximize work center utilization. The weight given to each of these objectives will depend on the competitive circumstances of the company and its prevailing manufacturing philosophy. For example, JUST IN TIME philosophies stress throughput time and due date performance above utilization.

## Forward and Backward Scheduling

Forward scheduling involves starting work as soon as it arrives. Backward scheduling involves starting jobs at the last possible moment to prevent them being late. The choice of backward or forward scheduling depends largely upon specific circumstances and gives different advantages and disadvantages. The main advantages of forward scheduling are, first, that utilization of work centers is high (if work is available it is scheduled to be performed by the work center), and, second, that the schedule remains flexible so that unexpected work can be loaded.

Backward scheduling, on the other hand, should progress material through the operation only when it is needed and therefore should keep work in progress inventory down. It is also less vulnerable to customers extending their required due date, but does tend to focus the operation on customer due dates (*see* FINITE AND INFINITE LOADING). In theory, both MATERIAL REQUIREMENTS PLANNING (MRP) and JIT use backward scheduling, only starting work when it is required. In practice, however, users of MRP may allow extra time for tasks to be completed, therefore each task is not started at the last possible time.

See also *Gantt chart; leveled scheduling; sequencing*

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## scientific management

*Michael Lewis*

The term scientific management (SM) came to prominence in 1911 with the publication by Frederick Winslow Taylor of a book of the same name. More generically, however, the late nineteenth and early twentieth centuries saw a number of management thinkers develop ideas and principles of JOB DESIGN and WORK ORGANIZATION that collectively became known as "scientific" management. By "scientific" Taylor meant management based on research and experiment rather than tradition, rule of thumb, guesswork, or personal opinion. In addition, Taylor (writing at a time of severe industrial unrest in North America) argued that managers and workers shared common interests: they would both benefit from lower costs and higher wages if managers adopted a rational, scientific approach.

Beyond its philosophical underpinnings, SM also incorporated a number of specific techniques, most of which are now core operations management (OM) tools: time and motion study (*see* PREDETERMINED MOTION TIME SYSTEMS; TIME STUDY); standardization of tools and procedures; clarity of task (approximately equivalent to goals or objectives); use of financial bonus; individualized work (groups act to distract); management training; scientific selection of staff; and shorter working hours and longer rests. Other contributors to the SM movement included Gilbreth, Gantt, and Bedaux. It is interesting to note that many of Taylor's "disciples" (e.g., the Gilbreths) helped to disseminate his ideas to prewar Japanese industry (e.g., shipbuilding).

From its earliest days, scientific management, and Taylor himself, attracted often quite vociferous criticism. Much of the criticism lacks validity but it is clear that excessive standardization can underplay the value of multiskilled or group based working in certain applications. Moreover, the excessive separation of planning and other "management" tasks from the routine and standardized operations tasks can deprive staff (and the firm) of a range of contributions and potential improvements. In conclusion, despite the enduringly pejorative implications of a "Taylorist" approach to work design, Taylor's influence on modern management is undeniable.

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## *Seiri*, *Seiton*, *Seiso*, *Seiketsu*, and *Shitsuke*

*Par Ahlstrom*

Simplicity and the elimination of waste are recurrent themes in JUST IN TIME and LEAN PRODUCTION. Complexity, clutter, and excessive paperwork are seen as alien to an excellent company. Several tools and techniques are deployed to transform previously complex, cluttered, and variable tasks into simple and clear tasks with increasingly low levels of variability and high levels of accuracy. These tools and techniques themselves tend to be relatively simple to understand and use. *Seiri*, *Seiton*, *Seiso*, *Seiketsu*, and *Shitsuke* (5Ss) is an example of such a tool. It is a housekeeping technique that necessitates little investment and is based on the idea that everyone can contribute to making their work environment cleaner, better, and safer, which is fundamental for QUALITY and PRODUCTIVITY.

First, materials and equipment are separated into those really needed and those not, with those not needed being thrown away. Next, each work area is organized for easy retrieval. Third, the workplace is cleaned and then standards introduced to maintain cleanliness. Finally, all previous tasks are made part of the daily routine. The 5Ss are intended to promote the discipline of cleanliness and tidiness as a set of shared values throughout the organization. If one cannot do the simple things right, the argument goes, then how can one do the more difficult things?

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## self-assessment models and quality awards

*Barrie Dale*

If a process of CONTINUOUS IMPROVEMENT is to be sustained and its pace increased, it is essential that organizations monitor on a regular basis what activities are going well, which have stagnated, what needs to be improved, and what is missing. Self assessment provides the frame work for generating this type of feedback about an organization's approach to continuous im provement. It helps to satisfy the natural curios ity of management as to where the organization stands with respect to the development of TOTAL QUALITY MANAGEMENT (TQM). (The rationale for using TQM rather than excel lence or business excellence is explained in Dale et al., 2000.)

Self assessment against the criteria of a qual ity award/excellence model on which to base the evaluation and diagnostics is now being given a considerable amount of attention by organiza tions throughout the world. The criteria of these awards encapsulate a comprehensive and holistic management model covering its various activities, practices, and processes and provide the mechanism for quantifying by means of a points score on the organization's current state of TQM development. There are many defin itions of self assessment provided by writers, but the European Foundation's definition of quality management is an all embracing one:

> Self-assessment is a comprehensive, systematic, and regular review of an organization's activities and results referenced against the EFQM Excellence Model. (EFQM, 1999)

The self assessment process allows the organiza tion to discern clearly its strengths and areas in which improvements can be made and culminates in planned improvement actions that are then monitored for progress.

There are a number of internationally recog nized models, the main ones being the Deming Application Prize in Japan, the Malcolm Baldrige National Quality Award (MBNQA) in the US, and the EFQM Excellence Model in Europe. Although there are some differences between the models, they have a number of common elements and themes. In addition, there are many national quality/excellence awards that are more or less duplicates of the international models, with some modifications to suit issues that are of national or local interest.

The models on which the awards are based and the guidelines for application are helpful in defining TQM in a way that management can easily understand in all types of organizations, small, large, public, private, manufacturing, and service. They help organizations to develop and manage their improvement activities in a number of ways. For example:

- They provide a definition and description of TQM, within a defined framework, which gives a better understanding of the concept, improves awareness, and generates owner ship for TQM amongst senior managers.
- They enable measurement of the progress with TQM to be made in a structured and systematic manner, along with its benefits and outcomes.
- Annual improvement is encouraged and this provides the basis for assessing the rate of improvement.
- They force management to think about the basic elements of their business and how it operates, and the relationship between their actions and results through this organiza tional change is facilitated.
- The scoring criteria provide an objective, fact based measurement system, help gain consensus within the organization on the strengths and areas for improvement of the current approach, and help to pinpoint the key improvement opportunities.
- Sharing of best practices (*see* BEST PRAC TICE) and organizational learning is facili tated.
- Education of management and employees on the basic principles of TQM is improved.

- A more cohesive company working environ ment is developed.

### Deming Application Prize

The Deming Prize was set up in honor of Dr. W. E. Deming back in 1951. It was in recognition of his friendship and achievements in the cause of industrial quality. The original intention of the Deming Application Prize was to assess a com pany's use and application of statistical methods; later, in 1964, it was broadened out to assess how TQM activities were being practiced. The award is managed by the Deming Application Prize Committee and administered by the Japanese Union of Scientists and Engineers (JUSE). It recognizes outstanding achievements in quality strategy, management, and execution. There are three separate divisions for the award: the Dem ing Application Prize, the Deming Prize for individuals, and the Quality Control Award for factories. The Deming Application Prize is open to individual sites, a division of a company, small companies, and overseas companies.

The Deming Application Prize is comprised of ten primary categories (see table 1), which in turn are divided into 66 subcategories. Each primary category has six subcategories apart from the quality assurance activities, which have 12 categories. To maintain flexibility, there are no predesignated points allocated to the individual subcategories. This checklist is prescriptive in that it identifies factors, proced ures, techniques, and approaches that underpin TQM. The applicants are required to submit a detailed document on each of the prize's criteria. The size of the report is dependent upon the number of employees in each of the applicant company's business units. The Deming Prize Committee examines the application document and decides if the applicant is eligible for on site examination. The Committee chooses two or more examiners to conduct this examination. Discussions with JUSE suggest that consider able emphasis is placed on the on site examin ation of the applicant organization's practices. It is also evident that the applicant organization relies a great deal on advice from the JUSE consultants. JUSE would also advise an organ ization when they should apply for the prize.

In 1996 the Japanese Quality Award was es tablished. This is an annual award that recog nizes the excellence of the management of quality. The concept of the award is similar to the EFQM model, with emphasis placed on the measurement of quality with respect to custom ers, employees, and society. The eight criteria on which the award is based are similar to the MBNQA.

### The Malcolm Baldrige National Quality Award

In a bid to improve quality management prac tices and competitiveness of US firms, the Mal colm Baldrige National Quality Improvement Act of 1987, Public Law 100 107, signed by President Reagan on August 20, 1987, estab lished this annual US quality award. The award is named after a former US Secretary of Com merce in the Reagan administration, Malcolm Baldrige, who served from 1981 until his death in 1987. The Baldrige National Quality Program is the result of the cooperative efforts of government leaders and American business. The purposes of the award are to promote an understanding of the requirements for performance excellence and competitiveness im provements and to promote the sharing of infor mation on successful performance strategies. The Baldrige National Quality Program guide lines contain detailed criteria that describe a world class total quality organization. The cri teria for performance excellence are available in business, education, and healthcare divisions. The National Institute of Standards and Tech nology (NIST), an agency of the US Department of Commerce, manages the program and award. The American Society for Quality (ASQ) admin isters the MBNQA under contract to NIST.

Up to two awards can be given each year in each of five categories: manufacturing business units, service business units, small business (de fined as independently owned and with not more than 500 employees), education organizations, and healthcare organizations. The latter two categories were introduced in 1999. Any for profit domestic or foreign organization and not for profit education or healthcare organiza tion located in the US that is incorporated or a partnership can apply. The US president makes the award, with the recipients receiving a spe cially designed crystal trophy mounted with a gold plated medallion. They may publicize and advertise their award provided they agree to share information and best practice about their successful quality management and improvement strategies with other American organizations.

Every Baldrige Award application is evaluated in seven major categories with a maximum total score of 1,000 (see table 1). The seven categories are subdivided into 18 items and 29 main areas to address further define the items. They embody 11 core values and concepts: customer driven excellence, visionary leadership, organizational and personal learning, valuing employees and partners, agility, focus on the future, managing for innovation, management by fact, public responsibility and citizenship, focus on results and creating value, and system perspective.

The evaluation is based on a written application (this summarizes the organization's practices and results in response to the criteria for

**Table 1** Quality award criteria

**(a) Deming Application Prize**

| *Category* |
|---|
| Policies |
| Organization |
| Information |
| Standardization |
| Human resources development and utilization |
| Quality assurance activities |
| Maintenance/control activities |
| Improvement |
| Effects |
| Future plans |
| Total |

**(b) Malcolm Baldrige National Quality Award**

| *Category* | *Max* |
|---|---|
| Leadership | 120 |
| Strategic planning | 85 |
| Customer and market focus | 85 |
| Information and analysis | 90 |
| Human resource focus | 85 |
| Process management | 85 |
| Business results | 450 |
| Total | 1,000 |

**(c) European Quality Award**

| *Category* | *Max* |
|---|---|
| Leadership | 100 |
| Policy and strategy | 80 |
| People | 90 |
| Partnerships and resources | 90 |
| Processes | 140 |
| Customer results | 200 |
| People results | 90 |
| Society results | 60 |
| Key performance results | 150 |
| Total | 1,000 |

performance excellence) of up to 50 pages and looks for three major indications of success:

- *Approach*: Appropriateness of the methods, effectiveness of the use of the methods with respect to the degree to which the approach is systematic, integrated, and consistently applied, embodies evaluation/improvement/learning cycles, and is based on reliable information, and evidence of innovation and/or significant and effective adoptions of approaches used in other types of applications or businesses.
- *Deployment*: The extent to which the approach is applied to all requirements of the item, including use of the approach in addressing business and item requirements and use of the approach by all appropriate work units.
- *Results*: The outcomes in achieving the purposes given in the item, including current performance, performance relative to appropriate comparisons and/or benchmarks, rate, breadth, and importance of performance improvements, demonstration of sustained improvement and/or sustained high level performance and linkage of results to key performance measures.

The assessors use these three dimensions to score an applicant. Approach and deployment are scored together and both must be adequately described to get a good score. However, it is "results" that separate the real contenders from the rest. High scoring on "results," which are heavily weighted toward customer satisfaction, requires convincing data that demonstrate both steady improvement over time, internally and externally, and that results are evaluated. Experience has shown that, even with a good internal approach and deployment strategy, it takes time for results to show.

Following a first stage review of the application, a decision is made as to which organizations should receive a site visit. The visits are used to verify information provided in the application and clarify issues and questions raised in the assessment of the application. A panel of judges reviews all the data both from the written applications and site visits and recommends the award recipients to the NIST.

### The European Quality Award

The European Quality Award (EQA) was launched in October 1991 and first awarded in 1992. The award is assessed using the criteria of the EFQM Excellence Model. The EQA was broadened in 1996 to include public sector organizations, and in 1997 a special category for small and medium sized enterprises (SMEs) (organizations of fewer than 150 employees) was introduced. Whilst only one EQA is made each year from the finalists in the categories of (1) large businesses and business units, (2) operational units of companies, (3) public sector organizations, and (4) SMEs, several European Quality prizes are awarded to those companies that demonstrate excellence in the management of quality through a process of continuous improvement, providing they also meet the requirements set annually by the jury. The EQA is awarded to the best of the prize winners in each of the four categories.

The EFQM Excellence Model is intended to help the management of European organizations to better understand best practices and to support them in their leadership role. It provides a generic framework of criteria that can be applied to any organization or its component parts. The model is based on eight fundamental concepts – results orientation; customer focus; leadership and constancy of purpose; management by processes and facts; people development and involvement; continuous learning, improvement, and innovation; partnership development; and public responsibility. The EQA is administered by the EFQM.

The model's criteria (see table 1) are split into two groups: "Enablers" and "Results." The scoring framework consists of 1,000 points with 500 points each being allocated to enablers and results. The nine elements of the model are further divided into 32 criteria parts. The model is based on the principle that processes are the means by which the organization harnesses and releases the talents of its people to produce results. In other words, the processes and the people are the enablers that provide the results. The results aspects of the model are concerned with what the organization has achieved and is continuing to achieve, and the enablers with how the organization undertakes key activities and how the results are being achieved.

The EFQM model is based on what is termed RADAR logic: results, approach, deployment, assessment, and review. The last four elements are used when assessing the enablers, and the results element is obviously used to assess results. The results cover what an organization achieves and looks for: the existence of positive trends and sustained good performance, com parisons with previous, current, and future targets, comparison of results with competitors and best in class organizations, understanding the cause and effect relationships that prompt improvements, and that the scope of the results covers all relevant areas. The approach covers what an organization plans to do along with the underlying reasons. It needs to be sound, sys tematic, appropriate, prevention based, focused on relevant needs, and be integrated with normal operations and support organizational strategy. The deployment is the extent to which the ap proach has been systematically deployed and implemented down and across the organization in all relevant areas. Assessment and review re lates to both approach and deployment. It will be subject to regular review cycles analysis and measurement, with appropriate learning and im provements planned, prioritized, and taken.

A 75 page report is required for large com panies and public sector organizations and 35 pages for SMEs. Once the application has been submitted to the EFQM headquarters, a team of trained independent assessors examines each ap plication and decides whether or not to conduct a site visit. The site visits provide an opportunity for the assessor to evaluate the application docu ment, in particular deployment issues, and to check issues that are not clear from the docu ment. Irrespective of whether or not the com pany is subject to a site visit, a feedback report is provided that gives a general assessment of the organization, a scoring profile for the dif ferent criteria, and a comparison with the average scores of other applicants. For each part criterion, the key strengths and areas for improvement are listed. A jury reviews the find ings of the assessors to decide the European Quality prize winners. The EQA is made to the organization judged to be the best of the prize winners in each of the four categories.

### The Self-Assessment Process

There are several methods by which an organiza tion may undertake self assessment. Each method has advantages and disadvantages and an organization must choose the one(s) most suited to its circumstances, varying in complex ity, rigor, and resources and effort. In general, organizations develop from using a simple ap proach to one more complex, unless they have some external stimulus affecting the pace at which they address the process. These methods are outlined in detail in the EFQM *Assessing for Excellence: A Practical Guide for Self Assessment* (EFQM, 1999). The broad approaches that can be used separately or in combination are:

- *Award simulation*. This approach, which can create a significant workload for an organiza tion, involves the writing of a full submission document using the criteria of the chosen quality award model and employing the complete assessment methodology including the involvement of a team of trained asses sors (internal) and site visits. The scoring of the application, strengths, and areas for im provement is then reported back and used by the management team for developing action plans.
- *Peer involvement*. This is similar to but less rigid than the award simulation approach in that there is no formal procedure for data collection. It gives freedom to the organiza tion undertaking the self assessment to pull together all relevant documents, reports, and factual evidence in whatever format they choose against the appropriate model being used.
- *Pro forma*. In this approach the criterion is described and the person(s) carrying out the assessment outlines the organization's strengths, areas for improvement, score, and evidence that supports the assessment in the space provided on the form. It is usual to use one or two pages per assessment criterion.
- *Workshop*. This approach is one in which managers are responsible for gathering the data and presenting the evidence to col leagues at a workshop. The workshop aims to reach a consensus score on the criterion

and details of strengths and areas for im provement are identified and agreed.

- *Matrix chart*. This requires the creation of an organization specific matrix or using one produced by one of the award bodies. It involves rating a prepared series of state ments, based on the appropriate award model, on a scoring scale. The statements are usually contained within a workbook that contains the appropriate instructions. The person(s) carrying out the assessment finds the statement that is most suited to the organization and notes the associated score.
- *Questionnaire*. This is usually used to carry out a quick assessment of a department or organization's standing in relation to the award model being used. It is useful for gathering a view on employee perceptions with respect to the criteria of the model selected. It involves answering a series of questions and statements, which are based on the criteria of the award model being employed, using a yes/no format or on a graduated response scale.

Ritchie and Dale (2000) have identified the following criteria that are necessary for a successful self assessment process:

- gaining commitment and support from all levels of staff;
- action being taken from previous self assess ments;
- awareness of the use of the model as a meas urement tool;
- incorporation of self assessment into the business planning process;
- not allowing the process to be "added on" to employees' existing workload;
- maintaining the self assessment skills of the assessors;
- getting the assessment done in time to link it into the business plans;
- developing a framework for performance monitoring.

The following criteria are identified as factors in an unsuccessful self assessment process:

- lack of commitment and enthusiasm;
- the time consuming nature of the process;
- not knowing where to start;
- selling the concept to the staff as something other than an "add on" to their existing duties;
- people not realizing the need for docu mented evidence;
- lack of resources, time, manpower, or finance;
- lack of cross functional integration between departments and units.

See also *benchmarking; breakthrough improve ment; business excellence model; quality manage ment systems; quality tools*

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## sequencing

*Nigel Slack*

Sequencing is the decision that is taken on the order of the jobs that will be tackled by a work station. Typically, in batch processes (*see* PRO CESS TYPES) and some SERVICE PROCESSES, each workstation has a queue of jobs waiting to be processed from which it must select one to work on. This is the sequencing decision. There are several sequencing rules that can be used to make this decision, including those described below.

Customer Priority

Operations may allow an important customer, or item, to be "processed" prior to others, irre spective of their order of arrival. This approach is typically used by operations whose customer base is skewed, containing a mass of small cus tomers and a few large, very important custom ers. However, sequencing work by customer priority may mean that "large volume" custom ers receive a very high level of service, while service to other customers is eroded. This may lower the average performance of the operation.

Due Date

Prioritizing by due date means that work is se quenced according to when it is due for delivery, irrespective of the size of each job or the import ance of each customer.

LIFO

Last in first out (LIFO) is a method of sequen cing usually selected for practical reasons. For example, unloading an elevator is more conveni ent on a LIFO basis as there is only one entrance and exit. However, it is not an equitable ap proach.

FIFO

Some operations process jobs in exactly the se quence in which they arrive on a first in first out (FIFO) basis. In high contact operations, arrival time may be viewed by customers in the system as a fair way of sequencing, thereby minimizing customer complaints and enhancing service per formance. However, because there is no consid eration of urgency or due date, some customers' needs may not be served as well as others. It is also difficult to be flexible in a system where this prioritization is visible to customers.

Longest Operation/Longest Total Job Time First

Under certain circumstances operations may feel obliged to sequence their longest jobs first. This has the advantage of occupying the work centers within the operation for long periods. Relatively small jobs progressing through an operation will take up time at each work center, which will need to change over from one job to the next. Espe cially where staff are under some incentive to keep utilization high, such a sequencing rule might seem attractive.

Shortest Operation/Shortest Total Job Time First

This rule involves choosing jobs to process on the basis of their processing time, either for their next operation or the sum of their process times. Because this rule launches shorter (faster) jobs through the system first, they are less likely to dwell in the system and slow down subsequent (slower) jobs. In fact, this rule is generally agreed to provide fast throughput and reasonably good due date performance on average. Its main disadvantage is that it can ignore larger jobs that may be continually superseded by later but shorter jobs. This means that a high "percentage on time" performance may be gained at the expense of a poor "average lateness" performance.

See also *delivery dependability; planning and con trol in operations; time based performance*

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**service design**

*Robert Johnston*

Many large and small service organizations employ rigorous and structured processes in the design and development of their services. "Few service organizations, unlike their manu facturing counterparts, employ specialist 'ser vice engineers' or use 'service laboratories' to help them design, test and evaluate their service processes. Service design is often an ad hoc or trial and error activity. Most faults and problems are effectively 'designed in,' albeit inadvertently, and as a result customers experi ence poor service and the processes are ineffi cient" (Johnston and Clark, 2001). The service design activity:

- is concerned with specifying the characteristics of service (*see* QUALITY CHARACTERISTICS);
- is concerned with designing out fail points (*see* FAILURE ANALYSIS; SERVICE RECOVERY);
- requires a clear understanding of customer needs and expectations and a clear and shared service concept (*see* SERVICE STRATEGY);
- involves decisions concerning the selection and training of staff and the design of jobs (*see* JOB DESIGN);
- includes the design of SERVICE TECHNOLOGY;
- involves the detailed design of the service delivery system, service package, service process, and the service environment (*see* SERVICE OPERATIONS).

### The Service Delivery System

The service delivery system, or the service operation, is the part of the organization that designs, creates, and delivers the service package to the customer. In many personal and social services it involves dealing directly with the customer, as in leisure and health services. In other organizations, the delivery system may be concerned with the provision of facilities for the customer, as in telecommunications and travel, or the provision of goods for the customer, as in retail and distribution activities. Within most service delivery systems there are two distinct types of operations, back office and front office. The back office is the part of the service operation that the customer does not usually see, nor has access to. This is often referred to as the "manufacturing" part of the service operation, for example, the kitchen in a restaurant. The front office is the part of the operation that provides the service to the customer, usually involving some contact with the customer, i.e., the place where the customer is processed.

### The Service Package

The service package comprises the bundle of goods used in the delivery of service or removed from the system by the customer, the environment in which the goods and services are provided, and the way the customers or their belongings are treated. Each service operation usually provides several services and several types of goods. These can be classified as the core, supporting, and facilitating goods and services (*see* TRANSFORMATION MODEL). The core service is the fundamental service of the organization, without which the remaining supporting and facilitating services would have little use. For example, the core service in a hotel is the provision of an acceptable bedroom. If this service was not provided, however excellent the hotel restaurant or however polite the staff, the "service" would have little point. Supporting services are the services that enhance the core service. Such services might include, in the case of a hotel, the restaurant, pool, recreation facilities, and tour services. Facilitating services facilitate the organization's provision of the core and supporting services. These activities may not directly involve the customer, for example, guest billing or cleaning in hotels.

### The Service Process

Service is often described as a process rather than a product, and whilst most services do process material objects and information, customer processing is usually a core and critical function. The customer process is the part of the front office that delivers the service package to the customer. This involves contact with the customer that may be personal and direct, e.g., face to face with a bank clerk, personal but indirect, e.g., discussing an overdraft with the bank manager over the telephone, or non personal and involve customers interacting with equipment, e.g., a cash machine. The provision of service involving contact and interaction with customers is usually a "real time" activity (*see* SERVICE PROCESSES).

### The Service Environment

Bitner (1992) coined the phrase "servicescape" to describe the physical surroundings of the service delivery system. She uses the word servicescape to convey more than just an environment; it refers to the "landscape" or backdrop that should give context to, and support for, the service concept. The physical setting and atmosphere of a service operation will influence the behavior and attitude not only of the service employees but also of the customers. Layouts can enhance or discourage social interaction, for example, decor can influence the perceived image of an organization. Other environmental cues, such as dress and furniture, can influence customers' beliefs about the nature of the service they are to receive.

Service Design Tools

There are a number of tools and techniques that can be used to aid the design of services. These include PROCESS MAPPING (sometimes re ferred to as BLUEPRINTING), process charts, QUALITY FUNCTION DEPLOYMENT, walk through audits, critical incident analysis (*see* CRITICAL INCIDENT TECHNIQUE), FAIL SAFING, and service transaction analysis (STA). STA (Johnston, 1999) is a combination of process mapping and walk through audits that assesses the customer's experience of a ser vice process. It comprises three key stages:

- agreement and specification of the service concept (the nature of the service offering);
- an assessment (and scoring) of the actual process by mystery shoppers, independent advisers, or consultant customers;
- identification of the reasons for the assess ment of each transaction.

From this assessment, service designers, man agers, and staff can begin to understand how customers interpret the service process and to discuss the improvements that can be made. The exercise can be repeated with a revised process and the profiles readily compared. STA at tempts to bring a systematic evaluation of a complete service process. It does not rely upon individual complaints or initiatives but analyzes and evaluates a process, step by step, from the customer's point of view. STA is a simple yet very effective analytical tool that can easily be employed by managers to increase the level of customer orientation of staff and can lead to speedy and easy improvements in service processes.

See also *service quality*

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### service operations

*David Collier*

Although the study of service operations is an increasingly important part of operations man agement (OM), it was not until 1978 that the first *Management of Service Operations* text (Sasser, Olsen, and Wyckoff, 1978) was pub lished: an extraordinary observation given that service industries typically account for 60–85 percent of employment in developed economies and that at least 50 percent of employment in goods producing industries is in SERVICE PRO CESSES. Today, it is generally accepted by both academics and practitioners that service oper ations are different, although defining precisely how they are different (i.e., what exactly defines a service operation, or indeed the service sector more generally) is not straightforward.

Some of the earliest formal definitions of ser vice, such as that of the US Standard Industrial Classification (SIC) – "organizations primarily engaged in providing a wide variety of services for individuals, businesses and government es tablishments, and other organizations" (US Government Printing Office, 1972: 295) – rely upon lists of examples ("amusements, hotel ser vice, electric service, transportation, the services of barber shops and beauty shops, repair and maintenance service, the work of credit rating bureau") to offer definitional precision. Unfortunately, such essentially empirical categorizations are insufficient (Judd, 1964) because they lack conceptual insight into what actually constitutes a service operation.

Over the last 20 years, therefore, many researchers have published definitions and typologies that seek to provide a better model of the components of service. Typical examples include all economic activities "whose output is not a physical product or construction, is generally consumed at the time it is produced, and provides added value in forms (such as convenience, amusement, timeliness, comfort or health) that are essentially intangible concerns of its first purchaser" (Quinn, Baruch, and Paquette, 1987: 50), or "that produce time, place, form, or psychological utilities" (Murdick, Render, and Russell, 1990: 4). What both of these definitions illustrate most completely is how problematic the definitional process can be. In the most general terms, service providing organizations exhibit four characteristics that are distinct from goods producing organizations.

- *Intangible*: If it is difficult to describe a service or demonstrate it to the buying public, this has significant operational and marketing implications.
- *Perishable*: Most services cannot be stored as inventory. In essence, the service manager is without the inventory "shock absorber" that is available to managers in goods producing firms to absorb fluctuations in demand. Correspondingly, the nature of short term demand places great pressures on service providers: arrival rates for services such as banks, airlines, supermarkets, and call centers are highly variable and difficult to forecast. For service delivery systems, capacity plays the same role as inventory: e.g., a hospital might have spare beds and a pool of temporary nurses as flexible capacity that will help it meet unanticipated patient demand.
- *Heterogeneous*: It is difficult to establish standards for the output of a service firm and even harder to insure that standards are met each time the service is delivered.
- *Simultaneity*: Services require simultaneous production and consumption, which compounds the problems caused by intangibility, perishability, and heterogeneity. Unlike a manufacturing system, consumers often interact with, and participate in, the service delivery process with production and consumption occurring simultaneously. As a result, service provider skills are central to successful service encounters.

Such a list is not exhaustive. In a comprehensive survey of the service literature, for instance, Cook, Goh, and Chung (1999) developed an integrated model of 12 "dimensions" defining different types of service, based upon the frequency with which they are mentioned: customer contact; tangibility; customer involvement; capital intensity; object of service; employee discretion; organizational ownership; commitment; customization; differentiation; type of customer (i.e., B2C or B2B); and production process.

See also *operations management; process technology; service design; transformation model*

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**service processes**

*Rhian Silvestro*

Process models have occupied a central position in the manufacturing operations management (OM) literature for decades. By contrast, there has been a distinct lack of agreement within the SERVICE OPERATIONS literature as to how to classify services so as to develop a corresponding understanding of the similarities and differences in the management of service operations. "Ser vice industries remain dominated by an oper ations orientation that insists each industry is different" (Lovelock, 1983).

The manufacturing process model is so dom inant in the OM field that attempts have been made to fit service examples into it. Such at tempts have met with considerable criticism be cause they are insufficient for diagnosing service systems and fail to capture the inherent variabil ity of service operations created by the existence of the customer in the process. A number of authors in the service management field have therefore proposed service typologies that more appropriately differentiate between different types of service. The distinctions described below by no means represent a complete list but include the main classification schemes in use.

- *Equipment or people focus*: Examples of equip ment based services include airlines, auto matic car washes, and vending machines; examples of people based services are appli ance repair and management consultants. This distinction attempts to move managers' strategic thinking away from a "product oriented language" to a service management approach that differentiates between busi nesses on the basis of the way in which service is provided. While the traditional assumption has been that services are invari ably and undeviatingly personal, as some thing performed by individuals for other individuals, the strategic requirements for equipment based businesses are obviously quite different from those in which individ uals perform services for other individuals. A similar distinction is that between differ ent types of services on the basis of the degree of labor intensity of the service process.
- *Level of customer contact*: Some authorities suggest classifying services along a con tinuum from high to low contact, where contact refers to the length of time the cus tomer is in contact with the service. This concept may also be operationalized slightly differently. Instead of considering the dur ation of customer contact, it may be prefer able to focus on where value is added, whether in the front or back office. It is then argued that services where value is added primarily in the back office are more akin to production operations and the lessons of modern production line management methods can be brought to bear.
- *Extent of customization*: Services can be dif ferentiated according to the extent to which they are tailored to meet individual require ments, an idea closely related to VARIETY. Customized activities involve compiling a service package for each customer. At the other extreme, standardized activities are non varying processes; although there may be several routes or choices, their availability is always predetermined. For example, rail transport systems provide passengers with a wide variety of routes between many loca tions, but the service offered cannot be tailored (at least in the short term) to meet individual passenger needs.
- *Degree of discretion in meeting customer needs*: This dimension can be defined as the extent to which customer contact staff exercise judgment in meeting individual customer needs. Clearly, the more highly customized the service process, the more discretion staff need to respond to customer requirements.
- *Product/process focus*: Some authors distin guish between product and process focused services. In a product focused organization the emphasis is on what the customer buys, while in a process focused business the em phasis is on how the customer buys, i.e., the

way the service is delivered. It is often argued that many service organizations tend to focus their control and measurement systems on product and outcome rather than on the process.

A multidimensional service classification scheme can be constructed drawing upon and integrating the typologies described above. Just as production VOLUME is the unifying characteristic in the manufacturing processes model, the volume of service activity, measured in terms of numbers of customers processed per business unit per period, similarly correlates with the service dimensions mentioned above. As the number of customers processed by a typical unit per day increases, the following service characteristics obtain:

- focus moves from a people to an equipment orientation;
- length of contact time moves from high to low;
- degree of customization moves from high to low;
- level of employee discretion moves from high to low;
- value added moves from front office to back office;
- focus moves from a process to a product orientation.

The framework, analogous to the manufacturing process model, is illustrated in figure 1, which identifies three service archetypes: professional services, service shops, and mass services. Just as there are hybrid manufacturing processes, not all services share all the characteristics of one service type, although most services will predominantly be characterized as either professional, service shop, or mass services. The three types of services are defined as follows.

- Professional services are organizations that process relatively few transactions, provide highly customized service, with relatively long contact time. These services tend to be people based, with most value being added in the front office, where considerable judgment is applied in meeting customer needs.
- Mass services are organizations where there are many customer transactions involving limited contact time and little customization. Often equipment based, the service offering is predominantly product oriented with most value being added in the back office and little judgment applied by the front office staff.

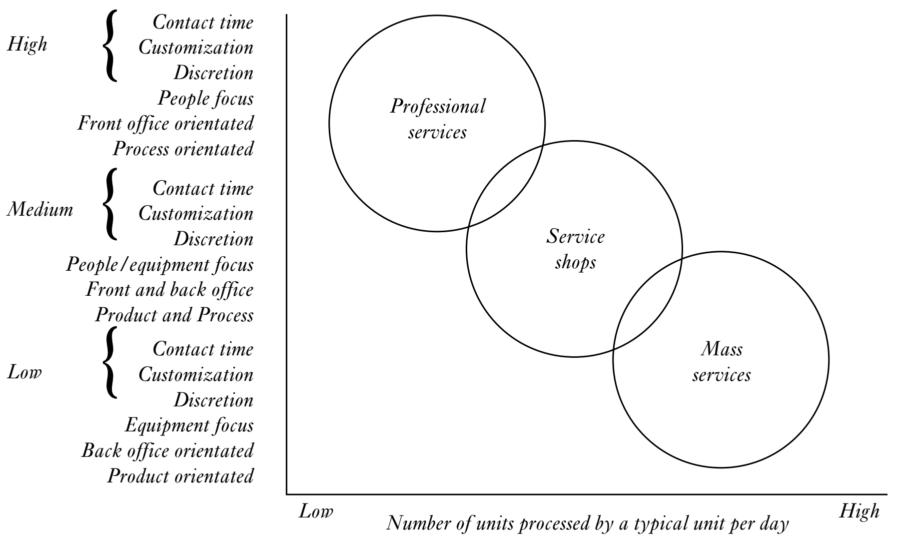


**Figure 1** Service processes

- The service shop is a categorization that falls between professional and mass services, with each of the service characteristics falling be tween the other two extremes.

### Professional Services

In customized service processes, the customer often actively participates in the process of de fining the service specification, detailing his/her individual requirements. Customers (or clients) of professional services typically build long term relationships with individual members of staff who will have personal responsibility for their individual customer accounts. The low volume of customers and the high relative value of their accounts mean that, for managers of professional services, customer retention (and the manage ment of SERVICE RECOVERY to obviate cus tomer defections) is likely to be a central concern. Being people based, the opportunities for substituting labor by equipment or technol ogy have traditionally been limited (*see* PROCESS TECHNOLOGY), while there is likely to be a high ratio of front office staff to customers. Human resource issues therefore tend to domin ate the resource management agenda. Key issues of labor intensive businesses are the hiring and training of staff, management, scheduling, and control of the workforce, and employee welfare.

The customized nature of professional ser vices, requiring high discretion by front line staff in meeting customer requirements, often means that front line staff are highly qualified, with valuable skills that are difficult to acquire. Controlling jobs in customized services is often highly complex due to the low specificity of tasks, limited repetitive learning opportunities, and the "craft skill specialization," making indi vidual work difficult to pace and standardize. Assignments are often long term and job com pletion times tend to be uncertain, variable, and difficult to estimate. Managing the career ad vancement of employees delivering the service, generating employee loyalty, and staff retention rates are likely to be key concerns. In addition, organization structures are likely to be flat, with loose rather than rigid control relationships be tween superiors and subordinates.

With labor being the key resource, control of labor costs is likely to be critical and labor PRODUCTIVITY will be the key measure of resource utilization. Costs are usually readily traceable in professional services with the price charged to the customer often being based on the number of labor hours spent on a job, making the use of diary systems to quantify, document, and control resources appropriate. Capacity is de fined primarily in terms of available labor in professional services. Such services tend to be more flexible in the short term than mass ser vices, being better able to accommodate changes to the service process and adjust capacity to meet demand fluctuations. Service flexibility tends to be provided through job scheduling, negotiation of delivery dates with the customer, multiskill ing, cross training, JOB ROTATION, and the transfer of staff between business units.

It could be argued that the nature of the customer relationship in professional services has implications for the control and measure ment of SERVICE QUALITY, which is essentially about the performance of staff. Investment in staff training, supervision, and chargeable ratios are typical quality measures in professional ser vices; for if there is inadequate investment in training, insufficient numbers of supervisory staff, and too much time spent on chargeable work, quality is likely to suffer. Formal quality audits and staff appraisals are also central to the control and measurement of service quality. Methods for the measurement of customer sat isfaction tend to be informal, being based on individual customer interviews and unstruc tured reports rather than standardized question naires or surveys. Unlike mass services, it is often feasible to measure the satisfaction of every customer rather than basing the measure ment on samples; and the identification of cus tomer dissatisfaction may well result in action being taken to recover the service for the indi vidual customer.

### Mass Services

Mass services are often equipment based and offer opportunities for the substitution of service by equipment or technology. In non labor in tensive mass services the choice of plant and equipment, and monitoring and implementing technological advantages, are likely to be key issues. Capacity tends to be defined in terms of availability of plant, equipment, and facilities and can be difficult to change in the short term.

Mass services therefore tend to be less flexible than professional services, not only in terms of their ability to change the service process, but also in terms of being able to adjust capacity to meet demand. Average response and throughput times are often built into the SERVICE DESIGN so that flexibility is designed into the system in the long term, with limited scope for short term flexibility. Level AGGREGATE CAPACITY MANAGEMENT and management of demand in order to smooth peaks and promote off peak demand therefore tend to be typical of the ap proach to CAPACITY MANAGEMENT.

Customer/staff relationships are best charac terized as being between the customer and the organization rather than with an individual, so given the limited scope for tailoring the service to meet individual needs, highly standardized services need to carefully manage customer ex pectations and invest in customer training. This may imply the preselection of customers, pro viding signals so that only customers whose ex pectations can be matched by the service delivery system actually select the service and participate in the process.

When levels of customer interaction are low, there are fewer opportunities to interface and therefore cross sell products and services to cus tomers than is typical in high contact, custom ized services. Similarly, efforts need to be focused on making the service environment "warm," even though there is limited scope for the provision of individual, personal attention. The nature of tasks for employees in high volume, standardized services may be highly specified, well defined, teachable, and of known duration. Workers therefore tend to become proficient in one type of operation and tasks may require staff who are tolerant of repetition. When demand is stable, units tend to be highly productive owing to the DIVISION OF LABOR, specialization, and learning that occur with scale. Control through the application of standard op erating procedures will be typical, with relatively rigid, hierarchical organization structures.

Part time and casual staff may well be used in mass services to increase flexibility in meeting different levels of demand, whereas in profes sional services the high skill levels of service providers and the length of time taken to train staff and bring them up to speed can prohibit short term recruitment possibilities. However, the opportunities for providing service flexibility through multiskilling and job rotation tend to be more limited than in professional services, since the trade off with productivity is costly. Service variety and choice is often provided to the cus tomer by giving many options and routes through the service process, making the tracing of costs of providing services to individual cus tomers very difficult. Therefore, typically, a high proportion of costs is allocated, so the prof itability of individual services may be difficult to ascertain.

Resource utilization is likely to be measured using a number of different ratios. Although labor productivity may well be an important indicator, ratios measuring the utilization of other resources are also likely to be used. The measurement of quality tends to be relatively routinized and systematic. Mystery shoppers and management inspections are typical mech anisms for monitoring quality, using standard ized checklists to evaluate service provision on a routine basis. Similarly, the measurement of customer satisfaction is usually formal and struc tured in mass services. Satisfaction will normally be measured on a sample basis and the identifi cation of customer dissatisfaction is unlikely to result in action being taken for the individual, but, rather, feeds into service design decision making.

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**service productivity**

*Colin Armistead*

For many years the (labor) productivity of service industries has been seen as lagging behind manufacturing. In fact, so prevalent was the hypothesis that productivity improvements in the service sector were harder to achieve because of the intrinsic characteristics of services that economists labeled it "Baumol's disease." More recently, however, the paradox of service productivity has become ever more puzzling as more and more services are dependent on labor saving capital equipment in the form of IT investment. This has led many researchers to reconsider how service productivity is measured, a process that is difficult for a number of reasons associated with the nature of the inputs and outputs from SERVICE PROCESSES.

These can be easily recognized by considering the problems associated with measuring and comparing the service productivity for a network of service branches that have a complex mix of inputs and outputs. Measuring inputs poses similar problems to manufacturing processes; however, measuring outputs poses specific problems for services. The intangible nature of service makes precise definition of outputs difficult. So the higher the intangible content of a service, the more difficult it is to define the output and hence to devise appropriate measures. Professional services present the greatest challenge. How, for example, might the output from a session with a psychoanalyst be defined? The situation is easier for mass services where the tangible aspect of the service rises, for instance, when providing information about travel times for trains or plane and travel prices.

The mix of services being offered though a common set of service resources also presents analytical difficulties. The greater the variety of service offered in a given time period, the more difficult it becomes to measure at an aggregate level. Professional services are more difficult in this respect than mass services. There is uncertainty as to whether the service output is constrained by lack of customer demand or other resources. The question is whether the service process is working at the rate set for the level of resources present to achieve the target levels of SERVICE QUALITY and productivity. If demand is erratic, and unless resource levels change, then the time at which measurements are made will influence the recorded service productivity. It is possible to establish the state of an operation by asking whether it is busy or slack for the resource level present at the time of measurement.

With respect to micro managerial decisions regarding service productivity, it is necessary to understand the balance between service quality and productivity. Although it may be possible to increase productivity by serving more customers, it has to be recognized that many operations choose not to adopt such a strategy if it might detrimentally affect service quality. Service productivity measurements should only be taken with a counter check on service quality and customer satisfaction.

Today, more effective multifactor measures of productivity have led economists (in the US at least) to conclude that since 1995 there has been a rapid acceleration in service productivity across nearly all sectors, driven in large part by a legacy of substantial IT investment. Indeed, the new measures have led several authors to question how poor the traditional productivity of the service sector ever was in reality.

See also *productivity; service operations; service technology*

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**service quality**

*Robert Johnston*

Service quality is defined in two different ways. Operational service quality is the degree to which the delivered service matches its design specification, whereas perceived service quality is the degree to which the service matches the customer's expectations or requirements (*see* QUALITY CHARACTERISTICS). Providing the operational specification matches the customer's requirement, these two approaches are the same. Any mismatches, however, may lead to customer dissatisfaction.

Operational service quality is under the con trol of operations managers. Using statistical process control techniques (*see* STATISTICAL QUALITY TECHNIQUES), managers are able to insure that the service delivered (as assessed by employees rather than perceived by customers) matches its specification. However, because many characteristics of a service are intangible and that service is perceived by customers rather than by the provider, many organizations use surveys, for example, to assess perceived service quality as a means of assessing delivered service. Perceived service quality is usually expressed in terms of the degree of satisfaction or dissatis faction of the perceived service compared to customers' expectations. Their expectations may be based upon, for example, price, previous experience, or word of mouth information and be influenced by the availability, or otherwise, and quality of alternatives.

### Expectations versus Perceptions

The notion of perceived service quality, i.e., perceptions versus expectations, has been de veloped from the disconfirmation theory. This theory holds that perceived service quality for a service is related to the size of the disconfirm ation experience, where disconfirmation is re lated to the person's initial expectations. More specifically, an individual's expectations are:

1. confirmed when a service or product per forms as expected;
2. negatively disconfirmed when the service or product performs more poorly than expected;
3. positively disconfirmed when the service or product performs better than expected.

Simply put, if the customer's perceptions were matched by his or her expectations, then the customer is satisfied with the service (*see* ZONE OF TOLERANCE). If the experience was better than expected, then perceived service quality is high and the customer is "delighted." If the experience did not meet expectations, then ser vice quality is perceived to be poor and the customer is dissatisfied. It is generally agreed that these three outcomes – satisfaction, delight, and dissatisfaction – are three states along a continuum of degrees of satisfaction.

Some organizations are content to define ser vice quality as matching perceptions with ex pectations. They might then design their service operation to try to reduce or remove any dissatisfying situations, whilst at the same time not necessarily trying to exceed expect ations as this may raise customers' expectations for future occasions, resulting in lower perceived service quality on the next occasion. Some leading edge organizations, however, are defin ing service quality as exceeding customer ex pectations and they continually seek ways in which they might delight their customers. Just as there is a range of outcome states, customers' expectations (i.e., that which the customer be lieves to be likely) are also usually regarded as being on a continuum whose scale goes from minimum tolerable to ideal, with desired, de served, and adequate being somewhere in between.

There is some controversy about the relative importance of expectations of overall service quality compared with the service performance itself. In some cases expectations may be a greater determinant of the perceived service quality; in other cases the service performance itself may be a greater determinant of the out come, especially where the customer has little prior knowledge of the service.

### Customer Satisfaction

Perceived service quality, i.e., confirmation or disconfirmation of expectations, leads to the emotion of satisfaction (or dissatisfaction). A service experience is often comprised of many individual service transactions or encoun ters, each of which will play a contributory part in the development of the customer's overall perception of the quality of the service. The outcome of each of these experiences has been defined as "service encounter satisfac tion," which is the consumer's satisfaction or dissatisfaction with a discrete service encounter. The customer's assessment of each encounter is based on the same expectation/perception model as overall service quality, but at a micro level. A customer's overall satisfaction or dissat isfaction with the total service experience, based on all the service transactions experien ced, is usually referred to as "overall service satisfaction."

It is this overall perception of satisfaction and dissatisfaction with the service that is tempered by other information, such as previous highly satisfying or dissatisfying experiences with the organization, or views about the overall value of the service relative to other alternative offerings of organizations. Together these factors create an impression of overall service quality in the customer's mind. Thus satisfaction with the ser vice may serve to reinforce feelings of service quality about a service.

## Service Quality Models

Several models have been developed and tested that have helped operationalize the service qual ity construct. The best known is that proposed by Parasuraman, Zeithaml, and Berry (1985), which identified four quality gaps that contrib ute to the fifth gap, a mismatch between expect ations and perceptions. The four gaps are: the gap between customers' expectations and man agers' perceptions of those expectations; the gap between managers' perceptions of service qual ity and the service quality specification; the gap between the service quality specification and that which is delivered; and the gap between that which is delivered and the external commu nications to the customers. By removing each of the four gaps, managers can minimize the fifth gap, that of expectations versus perceptions.

Several instruments have been designed to try to measure service quality. The best known is SERVQUAL developed by Parasuraman et al. (1988, 1994). SERVQUAL is a concise multiple item skeleton questionnaire that asks questions of customers about their expectations (minimum and desired) and perceptions of the services of a particular company. It encompasses five consoli dated quality dimensions, assurance, empathy, reliability, responsiveness, and tangibles, with 22 items for perceptions and 22 for expectations using a nine point Likert scale. A perception gap score is then calculated for each pair of statements (expectations versus perceptions), the difference being the SERVQUAL score. The instrument can also provide a measure of service superiority (perceptions versus desired level of service) and a measure of service ad equacy (perceptions versus minimum level of service).

## Return on Quality

Recent research has been concerned to explore the links between perceived service quality and satisfaction with customer loyalty, employee attitudes and satisfaction, and profit. In the main the relationships are positively correlated though not necessarily linear, and in some cases inverse relationships have been found (see, e.g., Silvestro and Cross, 2000). While many organizations have been focusing on as sessing customer satisfaction, it is clear that they need to better understand its impact on other business variables.

See also *critical incident technique; quality man agement systems*

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## service recovery

*Robert Johnston*

Service recovery is the action of seeking out and dealing with failures in the delivery of service (Johnston and Clark, 2001). A key, though often overlooked, role of service recovery is to support the drive for CONTINUOUS IMPROVEMENT by focusing managerial attention on specific prob lem areas. The critical issue about service recov ery is that it is not necessarily the failure itself that leads to customer dissatisfaction, as most customers do accept that things can go wrong. It is more likely to be the organization's response (or lack of response) to a failure that causes dissatisfaction. The crucial point is that whilst mistakes may be inevitable, dissatisfied custom ers are not.

If mistakes and failures are an inevitable part of service, then there are many opportunities for organizations to create very satisfied customers. Indeed, research has shown that most highly satisfying experiences encountered by customers are as a result of effective recoveries of ser vice failures. Service recovery has three key ingredients:

1 designing out failures to prevent them happening in the first place;
2 reactive service recovery (i.e., complaint handling);
3 proactive service recovery (i.e., seeking out problems and potential problems).

### Designing Out Failures

The best way of preventing failures and com plaints, thus eliminating the need for service recovery, is to prevent problems happening in the first place. Many failures and problems are the results of poor SERVICE DESIGN and there are many tools available to reduce the likelihood of failure (*see* FAILURE ANALYSIS).

### Reactive Service Recovery

Essentially, service recovery (and complaint handling) consists of three key operational activ ities:

1 *Dealing with the customer*: This involves ac knowledging that the problem has occurred, empathizing with the customer's predica ment, apologizing for the situation, taking ownership of the problem, and, if the prob lem is serious, involving managers.
2 *Solving the problem for the customer*: This involves fixing the problem for the customer and providing refund or compensation if required.
3 *Dealing with the problem within the organiza tion*: This involves finding the root cause, trying to insure the problem does not re occur, and providing reassurance to the cus tomer that it should not happen again.

### Proactive Service Recovery

Since many customers do not complain or bring problem situations to the attention of managers, rather than waiting to be told, managers need to seek out problems and potential problems. One way is to make it easy for customers to provide feedback; a second is for managers to actively evaluate services and SERVICE PROCESSES using walk through audits or service transaction analysis, for example.

### The Impact of Recovery

An organization's reaction to a problem needs to be measured and appropriate. The actions above depend on the context, the nature of the organ ization, the seriousness of the problem, the degree of dissatisfaction felt by the customer, the intrinsic value of the customer to the organ ization, and the cost of recovery and problem prevention.

On the other hand, research has shown that effective service recovery can significantly influ ence customer perceptions of SERVICE QUAL ITY, increase loyalty and repurchase intentions, and lead to positive word of mouth recommen dations. Wherever the responsibility for the fail ure might lie, customers have expectations of recovery, just as they do for the service itself, and thus organizations have the opportunity to satisfy or delight their customers when things go wrong. "While companies may not be able to prevent all problems, they can learn to recover from them. A good recovery can turn angry, frustrated customers into loyal ones" (Hart, Heskett, and Sasser, 1990). It is often suggested that organizations should see failure as an oppor tunity to create satisfied customers, reinforce customer relationships, and build customer loy alty. Leading edge organizations are those which have recovery systems in place. They believe that an effective response to failure has a high payoff in terms of customer loyalty and operational improvement.

Furthermore, it has also been shown that the lack of service recovery when a breakdown or failure has occurred has a dramatic negative effect on customer perceptions of service qual ity, loyalty, and repurchase intentions. Research has also found that the effect on word of mouth recommendations was significant: "Customers, we found, are searching for opportunities to get even. They don't tell the retailers, manufactur ers and service providers that they have served them poorly – they tell their friends and col leagues. As the bad word passes along, it creates a time bomb" (Davidow and Uttal, 1989).

See also *failure mode and effects analysis; risk and operations*

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## service strategy

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A service strategy (or a MANUFACTURING STRATEGY) provides the intellectual frame works and conceptual models that allow man agers to identify opportunities for bringing value to customers (Normann and Ramirez, 1993) and for delivering that value at a profit or within budget. The role for operations managers is to help create and deliver that value by contrib uting to the strategy debate and by developing the operation, its resources, people, and pro cesses, to provide for the future success of the organization.

A strategy is usually seen in market terms as an organization's plan to achieve an advantage over its competitors. Some organizations, how ever, may not wish to achieve advantage but see their role as maintaining their position in the marketplace. Others operate in non competitive situations and wish to insure that they are able to adapt to their own changing environments. Ser vice strategy can therefore be defined as the set of plans and policies by which a service organiza tion aims to meet its objectives. In this sense, service strategy is a means of directing and man aging change. It is not a one off activity as or ganizations need to respond to the two main forces of change that operate upon them, the external and internal environments. These changing internal and external conditions are the drivers of strategic change.

### Strategy Drivers

Modifications to service strategy may be driven by changes in the organization's external envir onment, either actual or anticipated. Such changes might include new competitors entering the marketplace or the strategic developments of competitors through different positioning or service developments, or the changing needs of customers as a result of the activities of the competition, or the loss of customers because their needs are not being met.

Changing internal conditions might include the requirements of the board or the sharehold ers for a greater return on assets or for expan sion, for example. Opportunities for change may arise from new developments from within the organization such as new services, skills, tech nologies, or processes. Change may be required because of declining staff loyalty or morale, which may in turn affect the level of service provided by the organization.

Without constant appraisal of the changes to the internal and external environments and con sequent adjustments to strategy, organizations may decay. Lovelock (1994) refers to this process as "institutional rusting." Strategy therefore in volves the process of continually checking the organization's plans for direction, progress, and cohesion in terms of the continually changing environment.

### Creating a Strategic Plan

A strategic plan should harness the various elem ents of an organization and insure that they support each other and are consistent with the direction indicated by the drivers of change. Five critical areas for service organizations in clude: (1) the creation of corporate objectives; (2) an understanding of the environment; (3) the development of an appropriate service concept and degree of focus; (4) the identification of appropriate operations performance objectives; and (5) the development of an appropriate deliv ery system.

*(1) Corporate objectives.* The development of clear corporate objectives is based on the strategy drivers: the internal or external pressures or opportunities for change. The objectives may well be expressed in financial or competitive terms over a set period of time, e.g., return on investment, profit, number of new customers, or market share. These objectives need to be clearly stated and will provide the means of measuring and monitoring the success or otherwise of the strategy.

*(2) The environment.* In order to insure that those objectives can be achieved, there is a need to develop a clear understanding of the market and the environment in which the organization currently operates, or plans to be operating. This will include an understanding of the size and nature of the competition, the nature and size of the market or potential market, existing com peting and complementary products and ser vices, the ways the market is currently segmented, and the likely reaction of the compe tition. One key outcome of this activity is the identification of a potential target market and an assessment of the perceived needs and expect ations of the target customers.

*(3) Service concept and focus.* The service con cept identifies the proposed nature of the busi ness, the service in the mind that the organization wishes to create. This helps the organization focus on the value that it can pro vide to customers. The development of a service concept may be based upon existing services, the activities in the external environment, or from internal drivers such as the activities of design departments or ideas of staff and man agers. The concept is a description of the form, function, purpose, and benefits of the service to be provided. The concept may require to be screened for viability, feasibility, and appropriateness and checked to insure that it will meet the needs and expectations of the target market.

The notion of FOCUS is an important one in assessing how an organization's service concept compares to, or is differentiated from, the offer ings of alternative organizations. Two dimen sions can be considered, the range of services provided and the scope of the target market. Service concepts may thus range from doing "everything for everybody" (unfocused) to those tightly focused on providing a narrow range of products to a small and well defined target market.

*(4) Performance objectives.* Having identified a target market and developed a service concept, the operation needs guidance as to how it should manage its resources and activities. This will insure that the service it provides will meet the corporate objectives and the needs of the target market, and establish how it will differentiate itself from the competition. Clear statements about the relative importance of price, QUAL ITY, availability, reliability, and flexibility, for example, are required to create an OPERATIONS

STRATEGY to guide the design and operation of an appropriate delivery system.

*(5) Delivery system.* The design of an appropri ate delivery system is a complex affair requiring decisions about the number and LOCATION of sites, the activities of each of the sites, the char acteristics of service, the selection and training of staff, the design of jobs (*see* JOB DESIGN), the design of SERVICE TECHNOLOGY, and the detailed design of the service delivery system, service package, service process, and the service environment (*see* SERVICE DESIGN). The con cept of focus at different levels in an organization can also be used to help identify the alternative ways of designing a service operation.

The critical questions that the design must answer include:

- Does the proposed design provide the de sired service concept?
- Is the design consistent with operations strategy and the operations performance ob jectives?
- Will it meet the perceived needs of the target market?
- How will it create value in the minds of customers?
- What will be the products and services?
- What is the relationship between core, sup porting, and facilitating products/services?
- How will the processes be designed?
- How will the services and products be moni tored and controlled?
- How will the operation cope with variation in demand without compromising the ser vice levels required?
- How can the operation harness energy within the organization to effect the changes required?

This detailed plan has then to be checked against the corporate objectives to insure that the total strategy is consistent and will achieve the object ives that have been set. Thus the process may have to go through several iterations before a consistent and cohesive strategy is created.

See also *manufacturing strategy process; operations objectives; service processes*

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## service technology

*Michael Lewis*

Setting aside the hyperbole, it is now widely accepted that technology will dominate the future of most services. Pragmatically, firms in a competitive marketplace invest in service tech nology for a variety of different reasons. For instance, capital investment in conjunction with rationalization/centralization can provide a platform for achieving significant economies of scale (*see* SERVICE PRODUCTIVITY). Tech nology can also help create cost and differenti ation advantage if it permits the marketing of additional services (economies of scope) through existing networks, thereby lowering marginal costs through shared overheads. Equally, cer tain technologies can enhance organizational decision making processes. For example, J. C. Penney, the US department store, introduced an information/communication technology (ICT) solution to allow all of its store managers to be involved in the central purchasing decision. Similarly, American Airlines gained several years' worth of competitive advantage by tracking its customers flying patterns more closely than its competitors, and many professional service firms utilize databases to retain experience despite high staff turnover rates.

In addition to describing many applications of technology to different service contexts, the aca demic literature focuses primarily upon typolo gies for classifying the nature of different service technologies. For instance, it is common to sep arate interactive, customer facing, and transac tion intensive, back office service technologies. Of course, technological investment can impact these processes in a variety of different ways, including automation, integration, disinterme diation, etc. It also often shifts the balance between those processes that directly deliver services to the market and those that act to maintain them. For example, in a supermarket where customers "self scan" their shopping, extra (maintenance) processes are required for CAPACITY MANAGEMENT, staff and customer training, security, and so on. Generically, service technology can be defined (adapted from Perrow, 1967) as "the collection of or ganizational resources that are employed in service transformation processes (i.e., those that result in a customer or information input being converted into a customer or information output)."

See also *advanced manufacturing technology; com puter integrated manufacturing; process technol ogy; service operations; service processes*

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**setup reduction**

*Alan Harrison*

Setup reduction (SUR) is often seen as one of the most directly useful techniques associated with JUST IN TIME philosophies of operations management. The purpose of SUR is to reduce the time, effort, and cost associated with changing a process from one activity to another. Traditional thinking in this area has been con strained by the economic batch quantity for mula, which models a perceived trade off between the carrying cost of inventory and a fixed setup cost (*see* ECONOMIC ORDER QUANTITY; INVENTORY RELATED COSTS; TRADE OFFS). The setup cost is determined by the time and resources necessary to change over equipment from good product of one type to good product of another. However, if setup times can be reduced, the benefits can be trans lated into reduced batch sizes.

The advantages of small batch sizes are that smaller batches are used quickly, so defectives are found earlier and corrective action taken earlier. More significantly, smaller batches mean that less inventory is needed and through put times are reduced. In general, material con trol becomes an easier task, and many of the routine transactions can be removed from cen tral systems and delegated to the shop floor. Similar principles apply to other operations that do not involve setting up machines. Assem bly lines that can be changed over more quickly from one product to another mean that shorter production runs can be planned.

Shingo's (1985) target for setups was encapsu lated in his "SMED system." SMED stands for "single minute exchange of dies" and reflects Shingo's view that setups can always be reduced to less than 10 minutes. Setup reduction has become fairly reutilized in many companies. A typical eight step approach (Harrison, 1992) is summarized here:

- *Step 1*: Select the setup to be tackled. Cri teria could include that it is the longest, or a bottleneck operation (*see* BOTTLENECKS).
- *Step 2*: Record the method as it currently stands. A popular way to record setups is by time lapse video.

- *Step 3*: Analyze the activities according to a classification scheme. This could include clamp/unclamp, load/unload, transport, adjustment, and cleaning activities.
- *Step 4*: Eliminate wasteful activities. Search time for tools can, for example, be eliminated by provision of a dedicated tool trolley.
- *Step 5*: Simplify remaining activities by, for example, presetting tools and improved ma terial handling devices.
- *Step 6*: Classify the remaining activities as internal work (which must be carried out after the machine has stopped) and external work (which must be carried out before the machine has stopped). The emphasis is on transferring internal to external work, and on reducing internal work to a minimum. This way, the machine is kept running for as long as possible, and the disruption of setups is kept as short as possible.
- *Step 7*: Develop methods and equipment to support the new internal and external activities.
- *Step 8*: Implement the new procedures as standard practice, and record the new method for training and as a challenge for further improvement.

Much of the literature on setup reduction em phasizes the low cost nature of the improve ments, such as elimination of search time referred to above. It is also significant that setup reduction along the above lines is carried out by the work teams themselves. While indus trial engineers could carry out this work, there are held to be many advantages to this approach. Team members "own" the solutions, and are therefore more likely to make them work effectively.

See also *breakthrough improvement; business excellence model; continuous improvement; JIT tools and techniques; sandcone model of improve ment*

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## SIMUL8 simulation package

*Andrew Greasley*

SIMUL8™ is a visual interactive modeling system based on the discrete event simulation method. A simulation can be constructed using a combination of work entry points, work centers, storage areas, and work exit points connected in an appropriate manner. SIMUL8 provides a rela tively low cost software platform for simulation development for student and business use.

For more information visit the website: http://www.simul8.com.

See also *business process redesign; process mapping; queuing analysis; simulation modeling; WIT NESS simulation package*

## simulation modeling

*Andrew Greasley*

Simulation is the use of models of organizational systems and processes, usually computer based, to provide a way of experimenting in order to understand their behavior in a number of scen arios. Organizational systems can be seen as a number of interconnected processes. Therefore, in order to improve the performance of an or ganization, it is necessary to study the design of these processes and the resources that they con sume. The construction of the model is thus designed to provide decision makers with detailed information on how processes behave. This understanding will assist in making deci sions that increase performance whilst minimiz ing problems from unforeseen side effects of change.

Simulation has been used for many years in manufacturing as part of the toolkit of the indus trial engineer. It has been an important element in a business context where global competitive pressures have forced manufacturers to develop increasingly efficient and effective process designs. With the advent of approaches to change such as business process reengineering (*see* BUSINESS PROCESS REDESIGN) and business process management (Smith and Fingar, 2003), the idea of a process perspective to design in service applications has become widespread. With the development of more sophisticated simulation software incorporating interaction and animation effects, the potential for simulation modeling as a tool for process improvement in all types of organizations is now being recognized. The main barrier to further use is the variety of skills needed in terms of PROJECT MANAGEMENT, data collection, statistical analysis, and model development to produce a useful model for decision making.

The term simulation is used to mean a number of things from a physical prototype to a video game. Here simulation refers to the use of a computer model to investigate the behavior of a business system. The use of a model on a computer to mimic the operation of a business means that the performance of the organization over an extended time period can be observed quickly and in a number of different scenarios. The simulation method usually refers to both the process of building a model and the conducting of experiments on that model. An experiment consists of repeatedly running the simulation for a time period in order to provide data for statistical analysis. An experiment is conducted in order to understand the behavior of the model and to evaluate the effect of different input levels on specified performance measures. Pidd (2003) characterizes systems best suited to simulation as:

- *Dynamic*: Their behavior varies over time.
- *Interactive*: They consist of a number of components that interact with one another.
- *Complicated*: The systems consist of many interacting and dynamic objects.

Most organizational systems have these characteristics and thus simulation would seem to be an ideal tool for providing information on the behavior of an organization.

Different types of simulation used in organizations include spreadsheet models, system dynamic simulations, and discrete event simulation.

A computer spreadsheet is an example of a numerical static model in which relationships can be constructed and the system behavior studied for different scenarios. Another example of a static numerical model is the Monte Carlo method. This consists of experimental sampling with random numbers and deriving results based on these. However, although random numbers are being used, the problems that are being solved are essentially determinate. The Monte Carlo method technique is widely used in risk analysis for assessing the risks and benefits of different, and often very expensive, decisions (*see* PROJECT RISK MANAGEMENT). Monte Carlo applications are sometimes classified as being simulations, but whereas simulation and Monte Carlo are both numerical computational techniques, simulation applies to dynamic models while Monte Carlo applies to static ones. Software such as CRYSTAL BALL™ allows the Monte Carlo method to be implemented on a computer spreadsheet.

Continuous simulation is used to model systems that vary continually with time. The concept of system dynamics uses this approach and has become popular as a tool to analyze human based systems and enable organizational learning (Senge, 1990). System dynamics attempts to describe human systems in terms of feedback and delays. Negative feedback loops provide a control mechanism which compares the output of a system against a target and adjusts the input to eliminate the difference. Instead of reducing this variance between actual output and target output, positive feedback adds the variance to the output value and thus increases overall variance.

Most human systems consist of a number of positive and negative feedback cycles, which makes them difficult to understand. Adding to this complexity is the time delay that will occur between the identification of the variation and action taken to eliminate it, and the performance of that action and its effect on output. What often occurs is a cycle of overshooting and undershooting the target value until the variance is eliminated. The system dynamics concept can be implemented using computer software such as STELLA II™ (Richmond and Peterson, 1994). A system is represented by a number of stocks (also termed levels) and flows (also termed rates). A stock is an accumulation of a resource such as materials and a flow is the movement of this resource that leads to the stock rising, fall ing, or remaining constant. A characteristic of stocks is that they will remain in the system even if flow rates drop to zero and they act to decouple flow rates. An example is a safety stock of fin ished goods which provides a buffer between a production system that manufactures them at a constant rate and fluctuating external customer demand for the goods.

Discrete event simulation is concerned with the modeling of systems that can be represented by a series of events. The simulation describes each discrete event, moving from one to the next as time progresses. When a discrete event simu lation is being constructed, the system being simulated is seen as consisting of a number of entities (e.g., products, people) that have a number of attributes (e.g., product type, age). An entity may consume work in the form of people or a machine, termed a resource. The amount and timing of resource availability may be specified by the model user. Entities may wait in a queue if a resource is not available when required. The main components of a discrete event simulation are as follows:

- *Event*: An instantaneous occurrence that may change the state of the system.
- *Entity*: An object (e.g., component, person) that moves through the simulation, activat ing events.
- *Attribute*: A characteristic of an entity. An entity may have several attributes associated with it (e.g., component type).
- *Resource*: An object (e.g., equipment, person) that provides a service to an entity (e.g., lathe machine, shop assistant).

For a discrete event simulation a system consists of a number of objects (entity) that flow from point to point in a system while competing with one another for the use of scarce resources (re source). The approach allows many objects to be manipulated at one time by dealing with mul tiple events at a single point in time on what is called the simulation clock. The attributes of an entity may be used to determine future actions taken by the entities.

In practice, discrete event simulation is most widely used and appropriate for applications that involve queuing – of people, materials, or infor mation. By simply defining in the simulation the timing of arrival to the queue and the availability of the resource that is being queued for, then the simulation is able to provide performance statis tics on the average time in the queue and the average queue size for a particular system. A simple example would be to determine the performance of a supermarket checkout system. From information provided on customer arrival rates and checkout service times, the simulation would be able to report performance measures such as average customer queue times and the utilization of the checkout resource. Queuing systems are prevalent and examples include raw material waiting for processing in a manu facturing plant, vehicle queuing in transporta tion systems, documents waiting for processing in a workflow system, patients waiting to be seen in a doctor's surgery, and many others. Examples of discrete event simulation systems include ARENA™, SIMUL8™, and WITNESS™.

Early simulation systems generated reports of system performance, but advances in soft ware and hardware allowed the development of animation capabilities. When combined with the ability to interact with the model, this tech nique became known as visual interactive simu lation (VIS). Most simulation modeling software is now implemented using graphical user interfaces employing objects or icons that are placed on the screen to produce a model. These are often referred to as visual interactive modeling (VIM) systems. Finally, because of the use of simulation in the context of business process redesign (BPR) and of other process based change methods, the technique is also referred to as business process simulation (BPS). The term business process modeling (BPM) is also sometimes used, but it is trad itionally related to information system develop ment tools.

In general simulation modeling is useful in providing the following assistance to the process improvement effort:

- *Allows prediction*: Predicts business system performance in a range of scenarios.
- *Stimulates creativity*: Helps creativity by allowing many different decision options to be tried quickly and cheaply.
- *Avoids disruption*: Allows an evaluation of a number of decision options without disruption or use of a real system.
- *Reduces risk*: Allows the evaluation of a number of possible scenario outcomes, permitting contingencies to be formulated for these outcomes and therefore reducing the risk of failure.
- *Provides performance measures*: Can be integrated into PERFORMANCE MEASUREMENT systems to provide organizational performance measures and cost estimates.
- *Acts as a communication tool*: The results and computer animation can provide a forum for understanding the system behavior. The dynamics of a system can be visualized over time, aiding understanding of system interactions.
- *Assists acceptance of change*: Individuals can predict the effects of change, thus allowing them to accept and understand change and improve confidence toward implementation.
- *Encourages data collection*: The systematic collection of data from a variety of sources necessary to build the model can in itself lead to new insights on the operation of the system, before the model has been built or experimentation begun.
- *Allows overview of whole process performance*: Using simulation to model processes across departmental boundaries allows improvement of the whole process, rather than the optimization of local activities at the expense of overall performance.
- *Acts as a training tool*: Allows personnel to be trained or provides a demonstration of process behavior without the possible cost and disruption to the real system.
- *Acts as a design aid*: Allows process behavior to be observed and thus optimized at an early stage in the process design effort.

Although simulation can be applied widely in the organization, a model developed for a nontrivial problem will consume a significant amount of resource in terms of staff time. Both time and cost elements need to be considered. Thus an assessment must be made of costs against potential benefits. As with many investment decisions, however, the costs are usually substantially easier to estimate than potential benefits, which may be of a more intangible nature, for example, the benefit of greater staff knowledge, which may lead to increased PRODUCTIVITY. Because of the significant cost of a simulation analysis, it is also important to consider alternative modeling methods that may provide the necessary information. These include such tools as spreadsheet analysis, queuing theory (*see* QUEUING ANALYSIS), and linear programming. However, it is important to be aware that although these tools may provide a quicker "decision," approaches such as queuing theory make a number of assumptions about the system being studied that can provide an inaccurate analysis.

The importance of the ability of simulation to model the variability characteristics of a particular system should be carefully considered in these cases. Although simulation can study more complex systems than many analytical techniques, its use may be of limited value for very complex or unpredictable systems. For example, human based systems, with staff who have discretion in their duties and how they undertake them, present a particular challenge. Even if a cost benefit analysis has been made in favor of simulation, a factor that can discount the approach is insufficient time available to complete the project. Activities such as data collection and model building may take longer than is available before a decision is required. The best policy is to consider the use of simulation at an early stage in the decision process. A possible solution is to employ consultants or simulation experts who can reduce the project duration by employing additional staff and can provide a faster model build through the knowledge gained from previous projects.

## Examples of Simulation Use

Simulation modeling is used in various areas of many different types of organizations. Some examples of simulation use are given below.

*Capital investment.* For large capital investments such as equipment and plant, simulation can reduce the risk of implementation at a rela tively small cost. Simulation is used to insure the equipment levels and plant layout are suitable for the planned capacity requirements of the facility.

*Manufacturing.* In order to remain competitive, manufacturing organizations must insure their systems can meet changing market needs in terms of product mix and capacity levels whilst achieving efficient use of resources. Because of the complex nature of these systems with many interdependent parts, simulation is used exten sively to optimize performance.

*Maintenance.* A key customer requirement of any delivered manufactured good or service sup plied is its reliability in operation, which is often a key measure of SERVICE QUALITY. Simula tion can test the performance of a system in a number of scenarios both relatively quickly and cheaply. Steps can then be taken in advance to insure service is maintained under various oper ating conditions.

*Transportation and logistics.* Transportation systems such as rail and airline services as well as internal systems such as AUTOMATED GUIDED VEHICLES (AGVs) can be analyzed using simulation. Many simulation software packages have special facilities to model track based and conveyor type systems and simulation is ideally suited to analyze the complex inter actions and knock on effects that can occur in these systems.

*Customer service systems.* The productivity of ser vice sector systems has not increased at the rate of manufacturing systems, and as the relative size of the service sector has increased, the potential increase in productivity from improving services has been recognized (*see* SERVICE PRODUCTIV ITY). The use of BPR and other methodologies to streamline service processes has many parallels in techniques used in manufacturing for many years. Simulation is now being used to help ana lyze many SERVICE PROCESSES to improve cus tomer service and reduce cost.

*BPR initiatives.* BPR attempts to improve or ganizational performance by analysis of a busi ness from a process rather than a functional perspective and then redesign these processes to optimize performance. Greasley and Barlow (1998) provide a case study of the use of simula tion in the context of a BPR project to redesign the custody operation in a UK police service.

*Health systems.* The emphasis on performance measures in government services such as health care has led to the increased use of simulation to analyze systems and provide measures of per formance under different configurations.

*IT systems.* Simulation is used to predict the performance of the computerization of pro cesses. This analysis can include both the process performance and the technical perform ance of the computer network itself, often using specialist network simulation software.

See also *process mapping; SIMUL8 simulation package; WITNESS simulation package*

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## simultaneous development

*David Twigg*

Simultaneous engineering (or CONCURRENT ENGINEERING, forward engineering, inte grated problem solving, parallel engineering, team approach, and life cycle engineering) is a generic term that has been applied to the process of overlapping different phases of design: "Sim ultaneous engineering attempts to optimize the design of the product and manufacturing process to achieve shortened lead times and improved quality and cost by the integration of design and manufacturing activities and by maximizing parallelism in working practices" (Broughton, 1990).

In studies of product (and service) develop ment projects, overlapping development phases are identified as a factor that can assist firms in reducing total development cycle time. Overlap ping development is where downstream activ ities receive resources prior to the completion, but after the start, of the upstream task. Two further types of overlapping development model can be identified: (1) those where successive tasks are undertaken in parallel, as information (and sometimes as technology) is transferred at each interface; (2) those where a greater overlap extends across several phases and, thus, several tasks may be undertaken simultaneously. In add ition to the benefits of faster speed of develop ment and increased flexibility, overlapping development aids the sharing of information and a variety of human resource management issues. Experience of successful users of overlap ping phases has shown that effective simultan eous engineering requires a combination of the early release of information, intensive two way flows of information, effective computer and organizational integration, analytical methods and tools, and multifunctional teams.

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## single-loop learning

*Michael Lewis*

In seeking to understand how to maximize or ganizational potential, scholars have identified a number of models of aggregate "learning." Ar guably, one of the most relevant to operations management (OM) is the model of single and double loop learning developed by Argyris and Schon (1978).

### The Advantages of Single-Loop Learning

In terms of an input/output TRANSFORM ATION MODEL, single loop learning (SLL) occurs when there is repetitive association be tween input and output factors. Statistical pro cess control, for instance, measures process output characteristics (product weight, electrical resistance, telephone response time, etc.) that can then be used to alter input conditions (sup plier quality, manufacturing consistency, staff training, etc.) with the intention of "improving" or "better controlling" the output.

Such forms of control can form a platform for strategic improvement, but the mechanism itself is only a form of SLL. Every time an operational error or problem is detected and corrected or solved, without questioning or altering the underlying values and norms of the organization, this is single loop learning. Given the import ance of such mechanisms to the ongoing man agement of operations, it is clear that they provide an organization with essential stabil izers. Without any great panic or calling of an extraordinary board meeting, the underlying op erational resources can become proficient at scanning their environment (internal and ex ternal) and monitoring general performance against generic performance objectives (cost, quality, speed, etc.), thereby providing essential stability.

### Downsides?

Unfortunately, the kind of "deep" system spe cific knowledge that is so crucial to effective SLL can, over time, help to create the kind of inertia that proves so difficult to overcome when an organization moves into a changing environ ment. Moreover, in a competitive environment, this kind of strength can be seen by competitors as exposing potential weakness. To simplify this greatly, one might compare the situation with that of a sportsman. Imagine a professional tennis player in the early 1980s – before the introduction of new materials in racket design – who has developed a devastatingly fast service game with his wooden racket. He wins nearly all of his points on serve, becomes known for his serve, practices his serves the entire time, in a tight game situation relies on his service to give him a boost, and so on. Knowing this, his op ponents cannot give up on trying to win service points but they begin to look for other weak nesses and probe these consistently, developing specific game plans to attack his (for instance) backhand stroke play. Then, with the introduc tion of new carbon fiber and graphite technol ogy into the game, suddenly everyone is serving 10 percent faster, and because serving is now a slightly different (and, with a much bigger "sweet spot" on the racket, slightly easier) pro cess, the relative advantage of his serve is radic ally diminished. It is then and only then that he really notices the relative weaknesses of his game in other areas and finds that he rapidly goes from being one of the best players on the tour to struggling to qualify.

All effective operations are better at doing what they have done before and this is a crucial source of advantage. At the same time that an operation develops its distinctive capability on the basis of limited search and learning patterns, however, it is exposing itself to risks associated with the things that it does not do well. Sustain able operations strategies therefore also need to emphasize DOUBLE LOOP LEARNING mech anisms that prevent the operation becoming too conservative and thereby effectively introducing delays and inappropriate responses to major change decisions.

See also *continuous improvement; high involve ment innovation; statistical quality techniques*

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## Six-Sigma

*Alan Betts*

Six Sigma is an approach to quality improve ment that was first popularized by Motorola, the electronics components, semiconductors, and communications systems company. When the company set its quality objective as "total cus tomer satisfaction" in the 1980s, it started to explore what the slogan would mean to its oper ations processes. It decided that true customer satisfaction would only be achieved when its products were delivered when promised, with no defects, with no early life failures, and when the product did not fail excessively in service. To achieve this, Motorola initially focused on re moving manufacturing defects. However, it soon came to realize that many problems were caused by latent defects, hidden within the design of its products. These may not show initially, but eventually could cause failure in the field. The only way to eliminate these defects was to make sure that design specifications were tight (i.e., narrow tolerances) and by improving process capability (in terms of the ratio of the specification range to the "natural" variability of the process).

Motorola's Six Sigma quality concept was so named because it required that the natural vari ation of processes ($\pm$ 3 standard deviations) should be half their specification range. That is, the specification range of any part of a prod uct or service should be $\pm$ 6 the standard devi ation of the process. The Greek letter sigma ($\sigma$) is often used to indicate the standard deviation of a process, hence the Six Sigma label. The number of defects produced by the process is expressed in terms of defects per million. The defects per million measure is used within the Six Sigma approach to emphasize the drive toward a virtually zero defect objective.

The Six Sigma approach uses a number of related measures to assess the performance of operations processes.

- A *defect* is a failure to meet customer required performance (defining perform ance measures from a customer's perspective is an important part of the Six Sigma ap proach).
- A *defect unit or item* is any unit of output that contains a defect (i.e., only units of output with no defects are not defective; defective units will have one or more than one defects).
- A *defect opportunity* is the number of differ ent ways a unit of output can fail to meet

customer requirements (simple products or services will have few defect opportunities, but very complex products or services may have hundreds of different ways of being defective).

- *Proportion defective* is the percentage or frac tion of units that have one or more defect.
- *Process yield* is the percentage or fraction of total units produced by a process that are defect free (i.e., 1 − proportion defective).
- *Defect per unit (DPU)* is the average number of defects on a unit of output (the number of defects divided by the number of items pro duced).
- *Defects per opportunity* is the proportion or percentage of defects divided by the total number of defect opportunities – the number of defects divided by (the number items produced \times the number of op portunities per item).
- *Defects per million opportunities (DPMO)* is exactly what it says, the number of defects that the process will produce if there were 1 million opportunities to do so.
- The *Sigma measurement* is derived from the DPMO and is the number of standard devi ations of the process variability that will fit within the customer specification limits.

Although based on the principles of statistical process control (*see* STATISTICAL QUALITY TECHNIQUES), Six Sigma incorporates several other approaches, all of which predated the Six Sigma construct. These include:

- customer driven objectives;
- use of evidence;
- structured improvement cycle;
- structured training connected to organiza tion of improvement;
- process capability and control;
- process design;
- process improvement.

An important element within the Six Sigma ap proach, like other concepts of CONTINUOUS IMPROVEMENT, is the idea that a literally never ending process of repeatedly questioning and requisitioning of the detailed working of a process or activity can encourage improvement. This repeated and cyclical nature of Six Sigma improvement is summarized by the idea of the DMAIC improvement cycle (*see* DMAIC CYCLE). This involves a structured use of the following stages: define, measure, analyze, im prove, and control.

The Six Sigma approach holds that improve ment initiatives can only be successful if signifi cant resources and training are devoted to their management. It recommends a specially trained cadre of practitioners, many of whom should be dedicated full time to improving processes as internal consultants. The terms that have become associated with this group of experts (and denote their level of expertise) are Master Black Belt, Black Belt, and Green Belt.

- Master Black Belts are experts in the use of Six Sigma tools and techniques as well as how such techniques can be used and imple mented. Primarily, Master Black Belts are seen as teachers who can not only guide improvement projects, but also coach and mentor Black Belts and Green Belts who are closer to the day to day improvement activity. They are expected to have the quan titative analytical skills to help with Six Sigma techniques and also the organizational and interpersonal skills to teach and mentor. Given their responsibilities, it is expected that Master Black Belts are employed full time on their improvement activities.
- Black Belts can take a direct hand in organ izing improvement teams. Usually, a Black Belt will have undertaken a minimum of 20 to 25 days' training and carried out at least one major improvement project over a three to six month training period. Like Master Black Belts, Black Belts are expected to de velop their quantitative analytical skills and also act as coaches for Green Belts. Again, like Master Black Belts, Black Belts are dedi cated full time to improvement, and al though opinions vary on how many Black Belts should be employed in an operation, some organizations recommend one Black Belt for every hundred employees.
- Green Belts work within improvement teams, possibly as team leaders. They have significant amounts of training, although less than Black Belts, typically around 10 to 15 days of training. Unlike Black Belts, Green

Belts are not full time positions. They have normal day to day process responsibil ities but are expected to spend at least 20 percent of their time on improvement projects.

See also *total quality management*

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## statistical quality techniques

*Barrie Dale*

Statistical quality techniques are generally taken to be those techniques that are used in managing QUALITY MANAGEMENT SYSTEMS and are based on the theories of applied probability (as opposed to the simpler "tools of quality manage ment"). Although the theory behind these tech niques has been known for many decades, their widespread use is more recent and connected with the increasing interest in quality related issues.

### Acceptance Sampling

Acceptance sampling is an inspection method in which decisions, based on a sample of the batch or product, are made to accept or reject a prod uct. It is founded on the mathematical theory of probability and employed in situations where there is a continuous flow of batches between supplier and customer. The general assumption is that a manufacturer presents batches to an inspector, who accepts or rejects them on behalf of a customer in light of clearly defined require ments. The manufacturer may be a department internal to an organization or an outside sup plier. In the case of the latter, acceptance sam pling is generally carried out at the customer's goods inwards department. It is sometimes a requirement of a major customer that a supplier take regular samples of its production output using acceptance sampling to determine whether or not the product is of an acceptable quality. The customer's quality management system standard will outline the circumstances where this is applied, along with the sampling plan to be used.

Sampling does involve risks that, although they cannot be eliminated, can be assessed by statistical techniques. The objective of a statis tically designed sampling plan is to insure that batches of the acceptable quality level (AQL), or better, have a high probability of acceptance and that batches with higher non conformity levels will almost certainly be rejected.

It is important that all decisions regarding acceptance or rejection of a batch of product are based on a random sample. Most sampling schemes relate sample size to batch size because of the need to insure a representative sample, which becomes increasingly difficult as the batch size increases. Accordingly, the penalty for rejecting a good batch or accepting a bad batch, based perhaps on insufficient sample data, also increases.

To be of value, sampling inspection has to be carried out in a systematic manner. The accept ance procedure can be based on attributes or variables data. The purpose of systematic sampling is to induce a supplier, through the economic and psychological pressure of batch non acceptance, to maintain a process average at least as good as the specified AQL, while at the same time minimizing the risk to the consumer of accepting the occasional poor batch.

Acceptance sampling is a screening technique based on after the event detection. The use of acceptance sampling by a customer at goods inward might be seen as diverting some of the responsibility for quality from supplier to cus tomer. Thus the customer's inspection becomes a vital ingredient in the supplier's quality control system. Furthermore, the idea of employing a certain proportion of defectives as a measure of the quality required in the product is contrary to the aim of trying to get suppliers to deliver batches of product that are free from non conformities and also to pursue CONTINUOUS IMPROVEMENT.

## Statistical Process Control

Statistical process control (SPC) is generally accepted to be management of the process through the use of statistical methods. It has four main uses:

- to achieve process stability;
- to provide guidance on how the process may be improved by the reduction of variation and keep it reduced;
- to assess the performance of a process;
- to provide information to assist with man agement decision making.

The first step in the use of SPC is to collect data to a plan and plot the gathered data on a graph called a control chart. The control chart is a picture of what is happening in the process at a particular point in time; it is a line graph. The data to be plotted can be in variable or attribute format.

Variable data are the result of using some form of measuring system. It is essential to insure the capability of the measuring system to minimize the potential source of errors that may arise in the data. The measurements may refer to prod uct characteristics (e.g., length) or to process parameters (e.g., temperature). Attribute data are the results of an assessment using go/no go gauges or pass/fail criteria. It is important to minimize subjectivity when using this pass/fail type of assessment. Reference standards, photo graphs, or illustrations may help and, where possible, the accept/reject characteristics should be agreed with the customer.

The objective of data collection is to get a good overall "picture" of how a process per forms. A data gathering plan needs to be de veloped for collection, recording, and the plotting of data on the control chart. The data collected should accurately reflect the perform ance of the process.

Different data gathering plans may give dif ferent pictures of a process, and there are many economic models of control charts. However, consideration of statistical criteria and practical experience has led to organizations formulating general guidelines for sample size and intervals between samples. For example, in the automo tive industry it has led to the widespread accept ance (for variables) of a sample size of five, a one hourly sampling frequency, the taking of at least 20 subgroups as a test for stability of a process, and the use of three standard error control limits. To obtain a meaningful picture of process performance from attributes data, and to insure that the statistical theory supporting the design of the control chart is valid, larger samples (no more than 25) and more subgroups are often required.

*Construction of control charts using variables data.* Control charts using mean and range are the most popular variables charts in use and they are now employed to discuss the methods of control chart construction. There are four steps to producing the chart.

1. Calculate each subgroup average ($\overline{X}$) and range value ($\overline{R}$); these data are plotted on the chart.
2. Calculate the process average ($X$) and pro cess mean range ($\overline{R}$). These statistics are plotted on the chart as heavy broken lines.
3. Calculate and plot on the chart the control limits. These control limits are drawn on the chart as solid lines and are set at three stand ard errors or $A_2$ ($\overline{R}$) for the mean control chart, and D4 ($\overline{R}$) and $D_{\mathcal{J}}$ ($\overline{R}$) for the range control chart from the reference value.
4. Analyze and interpret the control charts for special and common causes of variation.

The process average ($\overline{\overline{X}}$) is the mean of all the sample means, and the mean range ($\overline{R}$) is the average of all the sample ranges. These are used to calculate control limits and are drawn on the chart as a guide for analysis. They reflect the natural variability of the process and are calculated using constants, appropriate to the sample size, and taken from statistical tables.

*Interpreting a variables control chart.* The range and mean charts are analyzed separately, but the patterns of variation occurring in the two charts are compared with each other to assist in identi fying special causes that may be affecting the process. The range chart monitors uniformity and the mean chart monitors where the process is centered.

These causes of variation influence some or all of the measurements in different ways. They occur intermittently and reveal themselves as unusual patterns of variation on a control chart. Special causes should be identified and rectified, and, with improved process or product design, their occurrence should in the long term be minimized. It is important in the management and control of processes to record not only the occurrence of such causes, but also any remedial action that has been taken, together with any changes that may occur or have been made in the process. This provides a valuable source of information in the form of a "process log," to prevent the repetition of previous mistakes and in the development of improved processes.

Indications of special causes include the following:

- a data point falling outside the control limits;
- a run of points in a particular direction, consistently increasing or decreasing; in general, seven consecutive points is used as the guide;
- a run of points all on one side of the reference value ($\overline{\overline{X}}$) or ($\overline{R}$); in general, seven consecutive points is used as the guide;
- if substantially more or less than two thirds of the points plotted lie within the mid third section of the chart, this might indicate that the control limits or plot points have been miscalculated or misplotted, or that data have been edited, or that process or the sampling method are stratified;
- any other obvious non random patterns.

Common causes influence all measurements in the same way. They produce the natural pattern of variation observed in data when they are free of special causes. Common causes arise from many sources and do not reveal themselves as unique patterns of deviation; consequently, they are often difficult to identify. If only common cause variation is present the process is considered to be stable, hence predictable.

If properly maintained, the chart will indicate to operational personnel when they need to do something to the process and, on the other hand, when to do nothing. It discourages operators from interfering needlessly with the process.

*Construction of control charts using attribute data.* An argument in favor of inspection by attributes is that it is not such a time consuming task as that for variables, so the sample size can be much larger and it is also less costly to under take. Experience shows that attribute data often exist in a variety of forms in an organization, although they may not necessarily be analyzed statistically.

A variety of charts can be used to organize attribute data in order to assist with process control. The choice of chart is dependent on whether the sample size is kept constant and whether the inspection criterion is a non conforming item or a non conformity within an item. The main types of attributes chart for non conforming items are proportion/percentage ($p$) and number defective ($np$) charts, while for non conformities they are proportion ($u$) and number ($c$) charts.

The collection and organizing of data is almost identical to that described for variables, except that for each sample, the number (or proportion or percentage) of non conforming items or non conformities is recorded and plotted. The reference value on attribute charts is the process average. The control limits are again three standard errors from the process average. The interpretation of attributes data on control charts is similar to that for variables data.

The capability of the process is a measure of the acceptability of variation of a process. The simplest measure of capability ($C_p$) is given by the ratio of the specification range to the "natural" variation of the process (i.e., $\pm 3$ standard deviations).

$$C_p = \frac{UTL - LTL}{6\sigma}$$

where $UTL$ is the upper tolerance limit, $LTL$ is the lower tolerance limit, and $\sigma$ is the standard deviation of the process variability.

Generally, if the $C_p$ of a process is greater than 1, it is taken to indicate that the process is just "capable," and a $C_p$ of less than 1 to indicate that the process is not "capable," assuming that the distribution is normal.

The simple $C_p$ measure assumes that the average of the process variation is at the midpoint of the specification range. Often the process average is offset from the specification range, however. In such cases one sided capability indices are required to understand the capability of the process.

$$\text{Upper one sided index} C_{pu} = \frac{UTL - X}{3\sigma}$$

$$\text{Lower one sided index} C_{pl} = \frac{X - LTL}{3\sigma}$$

where $X$ is the process average.

Sometimes only the lower of the two one sided indices for a process is used to indicate its capability ($C_{pk}$):

$$C_{pl} = \min(C_{pu}, C_{pl})$$

See also *DMAIC cycle; quality tools; Six Sigma; total quality management*

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## strategic account management

*Simon Croom*

In business to business relationships, a strategic account is any large, complex customer that has special requirements. Strategic accounts are characterized by several common traits: a centralized, coordinated purchasing organization with multilocation purchasing influences, a complex buying process, large purchases, and a need for special services.

Strategic account management refers to the dedication of specialized systems, processes, and individuals to the management of the relationships to an individual customer. Critical success factors for strategic account management include organizational alignment between supplier and customer; senior management commitment; dedicated processes and systems for communications and knowledge management; clearly defined selection criteria for identifying the strategic account; long term account planning; the use of a range of sophisticated relationship and operational performance measurements metrics; and the development of profitable relationships for mutual (customer and supplier) benefits.

See also *outsourcing; purchasing; supply chain management*

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http://www.strategicaccounts.org.

## structural and infrastructural decisions

*Michael Lewis*

The myriad decisions that directly concern operations managers are often grouped together under a number of generic headings: for instance, capacity, technology, supply chain, performance measures, etc. Different writers on OPERATIONS STRATEGY use slightly different groupings and refer to them collectively in slightly different ways, such as operations policy areas, substrategies, or operations tasks. Regardless of the overall label, however, most works distinguish between structural and infrastructural decisions because of their very different characteristics.

Structural decisions are defined as those which shape the "building blocks" of the operation; they define its overall tangible shape and architecture. Infrastructural decisions, on the other hand, affect the people, systems, and culture that lubricate the decision making and control activities of the operation. The distinction between structural and infrastructural is sometimes characterized as analogous to that between hardware and software in computer based systems. Although there is some ambiguity as to which decisions are structural and which are infrastructural, structural decisions are normally taken to include those concerned with capacity, facilities and plant, technology, and VERTICAL INTEGRATION, whereas infrastructural decisions include those concerned with planning and control, quality management, new product or service development, and PERFORMANCE MEASUREMENT.

See also *manufacturing strategy; planning and control in operations; quality management systems; new product development process*

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## super bill

*Pamela Danese*

A super bill is a planning bill supporting the forecasting activity in contexts characterized by high product VARIETY (*see* FORECASTING PROCESS). It is a single level bill of material (*see* BILL OF MATERIALS) in which the "parent" is a pseudo (i.e., not real) product and the "children" are groups of items (Oden, Lan genwalter, and Lucier, 1993). The average prod uct's single level child codes in a super bill can be alternatively modular or kit bills. Modular bills contain components and parts that are either common to all the end product configur ations or related to each individual product option. Kit bills, instead, can be adopted when customers are not allowed to select among a set of recommended options (Orlicky, Plossl, and Wight, 1972). Kit bills contain components and parts that are either common to all the end product configurations or related to each indi vidual end product configuration. The use of super bills allows the reduction of the number of items whose demand needs to be estimated, as the forecast object shifts from many end product configurations to few aggregate product/item groups and improves the forecast accuracy as the forecast objects tend to be more aggregate.

As an example, suppose that a manufacturer produces food processors. Customers are allowed to select among a set of 36 ($3 \times 2 \times 3 \times 2$) end product configurations resulting from the combination of several options: three types of different power motors ("regular," "heavy duty," and "professional"), two types of bowl shape (cylindrical and spher ical), and three types of blades (type A, B, and C). In addition it is possible to require a pouring spout. The whole set of 36 end product config urations can be represented through a super bill. This planning bill represents an average, or pseudo, product that groups in separate child bills the common items (i.e., those included in all the end product configurations) and the individ ual option related codes. Moreover, planning bills incorporate percentage coefficients (*pc*) which indicate the probability that the child bills will be used. When such probability is less than 100 percent, a safety stock is required to compensate for forecast errors.

See also *family bill; kit bill; manufacturing re sources planning; modular bill*

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## supply chain alignment

*Pietro Romano*

When developing supply chain relationships, the initiating firm typically enters into an agreement based on a set of expectations about the potential for benefits, a time frame for achieving them, a history of behavior with the other companies in the supply chain that determines the trust worthiness of the organization, and a set of per ceptions about the trustworthiness of the other parties in turn. Initially, these expectations and perceived risks are communicated with the other parties and *alignment* occurs. The term align ment is important because it implies that the sets of mutual benefits expected on the part of both parties are congruent. Each part enters into the supply chain relationship assuming that every other party has certain responsibilities and duties that they will carry out in the future. This stage of the relationship is critical because it essentially determines the criteria by which the relationship will be deemed successful or not.

See also *network coordination mechanisms; supply chain coordination; supply chain integration; supply chain management*

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## supply chain coordination

*Pietro Romano*

Malone (1987) defines coordination as a pattern of decision making and communication among a set of actors who perform tasks to achieve goals. Coordination in a supply chain aims to properly manage materials, information, and finance flows. These flows are interdependent and, in some cases, substitute for one another. It is through the coordination of these flows that tremendous gains in the overall performance of the supply chain can be achieved. Coordination improves if all stages of the chain take actions that together increase total supply chain profits. Supply chain coordination requires each stage of the supply chain to take into account the impact its actions have on other stages. A lack of coordination occurs either because different stages of the supply chain have objectives that conflict, or because information moving between different stages becomes distorted. In fact, dif ferent stages of the supply chain may have ob jectives that conflict if each stage has a different owner who tries to maximize its own profits, resulting in actions that often diminish total supply chain profits.

See also *network coordination mechanisms; sup ply chain alignment; supply chain integration; supply chain management*

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## supply chain dynamics

*Christine Harland*

Industrial dynamics authors have applied elem ents of systems control theory to treat amplifica tion effects in supply chains. Much of the theory on which their work is based is attributed to Forrester (1961) and Burbidge (1961). They demonstrated that certain dynamics exist be tween firms in supply chains that cause volatil ity, and that this volatility increases for operations further upstream in the supply chain. This effect is also known as the "Forrester effect" and the "bullwhip effect."

Forrester's (1961) work considered a produc tion and distribution system whose component echelons were a factory, a warehouse, a distribu tor, and retailers. Between these he simulated flows of goods, information, and delays in the system. The effect he described is one where real demand information from the end of the chain is distorted as it is interpreted, processed, and passed up the supply chain. The distortion is amplified the further in the chain a company is from the consumer.

Some of the reasons why the Forrester effect occurs in supply chains relate to what has been called a just in case approach to managing materials. In contrast to a JUST IN TIME approach, just in case ordering has the following characteristics:

- Members of the supply chain keep safety stocks, just in case there should be a supply failure. Sometimes the orders they place are to replenish their safety stocks rather than because of a real end customer demand. The nature of the demand is not visible to their suppliers who endeavor to supply with the same vigor as if a real end customer were waiting.
- Orders are placed regularly and periodically rather than as and when they are needed. The order period tends to become greater the further upstream you go.
- Requirements are batched up to round numbers or to economic order quantities (*see* ECONOMIC ORDER QUANTITY), price break quantities, lot sizes, or minimum order quantities.

The principle was developed further by Bur bidge (1961), who described the relationship between process flow rate, fluctuations in demand, and inventory variation within a manu facturing operation. In 1984, Burbidge used the term "the law of industrial dynamics" and con cluded that: "If demand for products is trans mitted along a series of inventories using stock control ordering, then the demand variation will increase with each transfer."

The principles of industrial dynamics were applied in the 1990s to considering the manage ment of supply chains. Central to this is the recognition of perceived demand rather than real demand as being one of the causes of the Forrester effect. Lee, Padmanabhan, and Whang (1997a, b) explained the four major causes of the bullwhip effect, including (1) demand forecast updating, (2) periodic ordering/order batching, (3) price fluctuations, and (4) rationing and shortage gaming.

More recently, work has demonstrated the Forrester effect on perceptions in supply chains. Upstream relationships in supply chains suffered more from misperceptions between the purchaser/supplier than downstream rela tionships. This misperception was correlated to dissatisfaction in the relationships; i.e., upstream customers were more dissatisfied than down stream customers. So, in addition to the conven tional hard Forrester effect, this showed that supply chain dynamics also affected softer, be havioral aspects of the chain (Harland, 1995).

See also *inventory control systems; inventory man agement; purchasing; supply chain coordination; supply chain integration; supply chain manage ment; time based performance*

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### supply chain formalization

*Pamela Danese*

Formalization in the supply network context refers to "the degree to which the supply net work is controlled by explicit rules, procedures, and norms that prescribe the rights and obliga tions of the individual companies that populate it" (Choi and Hong, 2002). The supply network formalization dimension can be measured by analyzing the existence of agreements among supply network members, or of performance reports monitoring companies' behavior, or by analyzing the degree of standardization of deci sion making processes on the basis of systems of formalized procedures.

See also *network coordination mechanisms; supply chain alignment; supply chain coordination; supply chain management*

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## supply chain integration

*Pietro Romano*

The concept of integration as a mechanism to support business processes across a supply chain is closely related with the effort to over come intra and inter organizational boundaries. Thus, the very different perspectives authors adopt to deal with integration (i.e., functional, business process, information/materials flows, and information/communication technology in tegration) share the common aim to shift from local optimization to system optimization. Or ganizational integration aims to break the organ izational boundaries between functions and between companies. As to the functional bound aries, by overcoming them companies seek to better integrate different discipline and func tions, such as manufacturing, distribution, marketing, accounting, information, and engin eering. On the other hand, supply chain integra tion implies overcoming the company boundaries and working closely with suppliers and customers.

See also *network coordination mechanisms; sup ply chain alignment; supply chain coordination; supply chain formalization; supply chain manage ment*

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## supply chain management

*Simon Croom*

Organizations do not exist in isolation – they rely on resources and capabilities that are provided by the wider network of suppliers, customers, partners, collaborators, and other bodies in their broader environment. In recent years recogni tion of the importance of taking into account the dependencies and opportunities provided by other organizations has led to far greater aware ness and concern for the area of supply chain management (Gomes Casseres, 1994). Unfortu nately, there is not a single universal definition of supply chain or supply chain management. The term supply chain management was first used in its popular sense by Oliver and Weber (1982) and then replicated by Houlihan (1984, 1985, 1988) in a series of articles to describe the management of materials flows across organiza tional borders. It has continued to gain in sig nificance in the management literature since then and the definitions of supply chain manage ment have broadened to incorporate the tech nical and inter organizational systems involved in the end to end processes within the supply chain. "Technical" systems incorporate such materials and conversion processing activities as DESIGN, LOGISTICS, PURCHASING, pro duction, warehousing, and distribution. "Inter organizational" systems associated with supply chain management are primarily those such as supplier management, customer management, STRATEGIC ACCOUNT MANAGEMENT, and service relationship activities.

At its broadest, the term "supply" incorpor ates all of the operations processes from concep tion to death of a product or service. This embraces invention, design, material processing, production, assembly, exchange, distribution, and after sales support from the original source of raw materials through to the final consump tion and, often, destruction of the product or service. There is considerable interdependence between organizations in a supply chain and their network of suppliers, partners, collabor ators, service providers, and customers. The capabilities of suppliers and distributors, for example, have a direct bearing on the QUALITY, COST, and service performance experienced by the end consumer.

Harland (1997) differentiated between four levels of analysis that can be applied to the de scription of the structures relating to the concept of supply chains, namely: internal chain, dyad, supply chain, and network. This leads to three definitions that expose different perspectives on the nature of supply chain management.

1 *Supply chain management is the management of the internal supply chain*: When some or ganizations use the term supply chain man agement, they may be referring to the flow of materials and information from their imme diate suppliers, through their operation, and out through distribution to their immediate customers.
2 *Supply chain management is the formation of long term partnerships or relationships with suppliers*: "Partnership" sourcing involves forming stronger bonds between a purchas ing and a supplying organization whereby they work together to get business that bene fits both parties. Rather than a distant and confrontational relationship, partnership sourcing involves jointly improving design, reducing costs, improving quality, and de veloping products to market faster (*see* TIME TO MARKET).
3 *Supply chain management is managing the entire network of supply from original source through to meeting the needs of the end cus tomer*: The first definition concentrated on the firm and what went on, largely, inside it. The second definition concentrated on the relationship between elements of the chain. This third definition is broader still and re lates to the whole network. This implies managing beyond boundaries to develop strategies and influence, invest in, and con nect with suppliers, suppliers' suppliers, and so on upstream, as well as customers, cus tomers' customers, and so on downstream, ultimately to the end customer.

Even within this type of hierarchical definitional structure, there is a confusing profusion of over lapping terminology and meanings in the litera ture. As a consequence, many labels can be found referring to supply chain and to practices for supply chain management, including: inte grated purchasing strategy (Burt, 1984), supplier integration (Dyer, Cho, and Chu, 1998), buyer–supplier partnership (Lamming, 1993), supply base management, strategic supplier alliances (Lewis, 1995), supply chain synchronization (Tan, Kannan, and Handfield, 1998), network supply chain (Nassimbeni, 1998), value added chain (Lee and Billington, 1993), lean chain ap proach (New and Ramsay, 1995), supply pipe line management (Farmer and Ploos van Amstel, 1990), supply network (Nishiguchi, 1994), value stream (Hines et al., 2000). (See also Thomas and Griffin, 1996; Cooper, Lambert, and Pagh, 1997; Copacino, 1997; Babbar and Prasad, 1998; Narasimhan and Jayaram, 1998; De Toni and Nassimbeni, 1999; Narasimhan and Das, 1999; Lummus and Vokurka, 1999; Croom, Romano, and Giannakis, 2000; Lamming et al., 2000; Frohlich and Westbrook, 2001; Tan, 2001; Ho, Au, and Newton, 2002; Svensson, 2002a, b.)

In an attempt to deal with the complexity surrounding not just the terminology but also the nature of supply chain management, a number of academic papers have attempted to provide integrative conceptual models (Croom et al., 2000; Larsson and Halldorsson, 2002; Mouritsen, Skjott Larsen, and Kotzab, 2003; Giannakis and Croom, 2004). Some common themes, however, are emerging in this debate.

First, any organization, whether a large cor poration, public body, or small business, has to meet the needs of its various customers and users, will need resources in order to do this, and will acquire many of its materials, equip ment, facilities, and supplies from other organ izations. The performance of each organization is thus influenced to a greater or lesser degree by the actions of managers within all of the organ izations that make up the supply chain. Indeed, it is now a widely argued view that competition takes place between supply chains, not just individual organizations (Christopher, 1998).

Second, supply chain management is concerned with the management of interconnected operations processes. This perspective sees the supply chain as made up by suppliers' operations processes serving their customers' operations processes (Slack and Lewis, 2002). Many organizations have also recognized that their performance depends on the capability of their suppliers' operations to deliver goods and services in an appropriate manner. In the auto industry, Ford Motor Corporation and others invest heavily in providing technical and operations support for their suppliers and audit their suppliers' processes regularly. Suppliers are expected to be focused on improvements in the cost, quality, and responsiveness of the operations. In their groundbreaking research, Womack, Jones, and Roos (1990) found that world class auto manufacturers focused on process excellence across their supply chains, particularly in driving increased efficiency through the adoption of "lean" process design and methods (*see* LEAN PRODUCTION).

Third, effective supply chain management involves considerable attention to the nature of relationships between the various organizations and "actors." The IMP Group in particular (Ford et al., 2003) use transaction cost theory to explore the significance of relationship management between the dyads (customer–supplier links) in the supply chain. The closeness of relationships between the various parties to a supply chain may range from an "arm's length" (or market) relationship to an integrated, collaborative relationship. Japanese industries have often been held up as exemplars of the benefits of close, "partnership" relationships. By fostering close mutual dependency and integrating technical expertise and market development, many Japanese companies are considered to have achieved their world class status directly through close collaborative supply chain relationships (Lamming, 1993).

Fourth, considerable research has been conducted into the problems and characteristics of coordinating materials and information flows throughout the supply chain. A primary problem for supply chain management is to address the consequences of the "bullwhip" or "Forrester" effect (Forrester, 1961; Lee, Padmanabhan, and Whang, 1997; *see* SUPPLY CHAIN DYNAMICS). This refers to the tendency of supply chains to amplify and disrupt materials order quantities and inventory levels as each successive link in the chain responds to their immediate customer's orders. The bullwhip effect is caused by each link in the chain taking independent decisions regarding safety stock levels, order quantities, and forecasting. Furthermore, the existence of time delays between each link (order lead time) compounds the bullwhip effect by reducing attempts to synchronize the total chain. Supply chain management in the retail, industrial, and technology sectors is increasingly attempting to address these bullwhip effects. Failure to meet demand or incurring excess costs of stock are significant for today's multinational supermarket chains with their global sources of supply. Consequently, they are adopting initiatives such as COLLABORATIVE PLANNING, FORECASTING, AND REPLENISHMENT (CPFR) or efficient customer response (ECR) to focus on improving availability of products to consumers. This involves coordinating the production, distribution, stock levels, and delivery across the main links in the supply chain, increasingly aided by integrated information systems that provide real time sales, scheduling, and tracking information.

Marshall Fisher (1997) provides a valuable framework ("the Fisher framework") for determining the relationship between the nature of market demand and the focus of supply chain design. He stated that for products with a stable (or "functional") demand, organizations should concentrate on efficiency in their supply chains (often called "lean supply chain management"). Where their demand is highly variable as a result of seasonal patterns, short life cycles, or promotional activity, then the focus should be on developing responsive supply chains (often called "agile supply chain management").

See also *capacity strategy; design chain; international location; operations strategy; physical distribution management; vertical integration*

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## supply chain risk pooling

*Pietro Romano*

Risk pooling is an important concept in SUPPLY CHAIN MANAGEMENT. It suggests that demand variability is reduced if one aggregates demand across locations because, as demand is aggregated across different locations, it becomes more likely that high demand from one customer will be offset by low demand from another. This reduction in variability makes it possible to reduce safety stock and therefore reduce average inventory. Simchi Levi, Kaminsky, and Simchi Levi (2000) compare a centralized and a decentralized distribution system and highlight that the variability faced by the central warehouse in the centralized system, measured by the standard deviation, is much smaller than the combined variabilities faced by the two warehouses existing in the decentralized system.

See also *network coordination mechanisms; supply chain alignment; supply chain coordination; supply chain formalization; supply chain integration*

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## supply management

*Simon Croom*

Supply management is a term that is usually used to indicate an organizational function or management activity that focuses on the management of relationships and improvement of the supply side (or "upstream") channels of an organization's supply chain. By forging and managing alliance relationships with key suppliers, organizations aim to benefit from their collaborative strategies in the form of improvements in the DESIGN, production, delivery, and service of products. Supply management emphasizes total supply chain approaches to COST, QUALITY, and timing in a wide range of industries including defense, auto, pharmaceutical, financial services, and healthcare. Some authorities argue that supply management is the "next phase" of evolution of the PURCHASING function toward an integrated approach to SUPPLY CHAIN MANAGEMENT (Burt, Dobler, and Starling, 2003).

See also *make or buy; outsourcing*

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**supply network centralization**

*Pamela Danese*

In supply networks, centralization is related to how much authority or power is concentrated or dispersed across the supply network (Choi and Hong, 2002). If the decision making authority in a supply network is mainly concentrated on a single supply network member, the supply net work is said to be centralized. Conversely, if decision making authority is distributed among supply network members, the supply network is said to be decentralized. The decision making process can regard different processes such as product engineering, production planning, order replenishment, or forecasting activities.

See also *network coordination mechanisms; supply chain alignment; supply chain coordination; supply chain management*

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**supply network complexity**

*Pamela Danese*

In supply networks, complexity regards both the complexity of the supply network structure and the complexity of the relationships among supply network members (Choi and Hong, 2002). Structural complexity can be measured through three variables: (1) the horizontal com plexity, (2) the vertical complexity, and (3) the spatial complexity of the supply network. The vertical complexity depends on the number of tiers within the supply network. The number of actors in each tier represents the horizontal com plexity. Finally, the average distance between two firms in the supply network is its spatial complexity. Moreover, as suggested in the lit erature on organization design (Dooley, 2001), an additional important measure of complexity is the level of coupling between firms in the supply network, which can be evaluated, for example, by investigating the existence of shared history, switching costs, closeness of working relation ships, and so on.

See also *network coordination mechanisms; supply chain alignment; supply chain coordination; supply chain management*

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**supply network information systems**

*Pietro Romano*

Supply network information systems, also known as inter organizational information systems (IOIS), are systems based on informa tion technologies that cross organizational boundaries. In fact, at the ultimate level of inte gration, all member links in the supply chain are continuously supplied with information in real time. Five basic levels of participation for indi vidual firms within the inter organizational system have been identified by Barrett and Kon synski (1982):

1 *Remote I/O node*, in which the member par ticipates from a remote location within the application system supported by one or more higher level participants.
2 *Application processing node*, in which the member develops and shares a single appli cation, such as an inventory query and order processing system.
3 *Multiparticipant exchange node*, in which the member develops and shares a network interlinking itself and any number of lower level participants with whom it has estab lished business relationships.
4 *Network control node*, in which the member develops and shares a network with diverse applications that may be used by different types of lower level participants.

5 *Integrating network role*, in which the member literally becomes a data communication/data processing utility that integrates any number of lower level participants and applications in real time.

According to Handfield and Nichols (1999), a sixth level of participation also appears within the context of the supply chain in which the participant shares a network of diverse applications with any number of participants with whom it has established business relationships (*supply chain partner node*). This level is similar to Barrett and Konsynski's fourth level but does not restrict the IOIS participants to a specific level, as they may be at a level lower, higher, or equal to the IOIS sharing organization.

See also *network coordination mechanisms; supply chain alignment; supply chain coordination; supply chain management; supply network centralization*

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## system loss

*David Bennett*

System loss is a phenomenon that occurs with PRODUCT LAYOUT, or lines, when tasks are being carried out by human operators rather than being automated. Where operators are involved they are often subject to "pacing," which is the need to keep working at the speed of the line. Since the work times of any operator will inevitably be subject to natural variability, lines are designed such that the cycle time allows the operator at the busiest workstation to complete the task (*see* WORK TIME DISTRIBUTIONS).

System loss in such paced lines is the loss that occurs when operators either cannot complete all their work within the cycle time or have idle time on a cycle. It is particularly prevalent on mixed model lines where the variability of work times is greatest. The effect of system loss is that either the line needs to be stopped for work to be completed, or products remain unfinished at the end of the line and need to be completed later, or workers further down the line are forced to have idle time.

Normally, system loss can be minimized by increasing the time for which items are available to operators. This can be achieved in two ways; first, by slowing down the line while reducing the distance between products (thereby retaining the same cycle time), and second, by introducing a buffer stock of parts between each workstation to "absorb" any losses that occur due to excessive work times. However, despite these measures, losses cannot be totally avoided where lines are being used because there will always be unexpectedly long work times due to unforeseen circumstances. The only way to completely solve the problem of system loss is to use a wholly different approach, such as a CELL LAYOUT, which is not subject to pacing.

System loss can also occur in unpaced lines that consist of a series of workstations with interstage buffer inventories. If, over a period of operation, a preceding station processes several items at times shorter than its succeeding station, the available buffer inventory space will eventually become full, forcing the preceding station to cease work. This is called "blocking." Conversely, if the succeeding station processes several items faster than its supplying station, it will exhaust the buffer inventory and have no items to work on. Again this will cause the station to stop work, this time through "starving." Together, blocking and starving result in system loss.

In such unpaced lines the degree of system loss will depend on the extent of variation in the station's individual work time distribution, the number of stations arranged in series, and the amount of buffer inventory space provided between each stage. System loss will increase with increasing work time variation and the number of stages, but reduce with increasing buffer inventory space. However, larger inven tory space will mean higher work in progress levels.

See also *balancing loss; business process redesign*

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# T

## Taguchi methods

*Nigel Slack*

Taguchi "methods" are normally used as a label for two separate but related sets of ideas. The first is that, by the use of statistical methods aimed at developing an understanding of variance, experiments may be constructed that enable the critical design factors responsible for degrading product performance to be identified. The second idea is that in judging the effectiveness of designs, the degree of degradation or loss is a function of the deviation of any design parameter from its target value.

The first of these ideas was reportedly developed by Dr. Genichi Taguchi when he worked at the Japanese telecommunications company NTT in the 1950s and 1960s. His concept of off line quality control involved attempting to attain both high quality and low cost design solutions through the effective use of experimental techniques. He proposed that the design process should be seen in three stages:

1. Systems design is intended to identify the basic elements of the design that will produce the desired output, such as the best combination of processes and materials.
2. Parameter design takes the system design elements of the design and sets the most appropriate parameter values for them. This stage identifies the "settings" of each parameter that will minimize variation from the target performance of the product.
3. Tolerance design identifies the components of the design that are sensitive in terms of affecting the quality of the product and establishes tolerance limits that will give the required level of variation in the design.

Taguchi methodology emphasizes the importance of the middle (parameter design) stage, a stage that, it is argued, is often neglected in normal industrial design practice. The Taguchi methodology proposes identifying the parameters that are under the control of the designer, and conducting a series of experiments to establish the parameters that have the greatest influence on the performance and variation of the design. Through this approach, designers are able to identify the aspects of a design that most influence the desired outcome of the design process.

The second related aspect of Taguchi methodology is the "quality loss function." This holds that there is an increasing loss, both for producers and for society at large, which is a function of the deviation or variability from a target value of any design parameter that represents the "ideal state" of that parameter. The greater the deviation from target or variability, the greater is the loss (*see* ZONE OF TOLERANCE).

The concept of loss being dependent on variation has always been well established in design theory, and at a systems level is related to the benefits and costs associated with dependability. Variability inevitably means waste of some form. However, operations managers (especially service operations managers) realize that it is impossible to have zero variability. The pragmatic response has traditionally been to set a target level for performance and a range of tolerance about that target which represents acceptable performance. This is usually interpreted in practice as implying that if performance falls anywhere within the range, it is regarded as acceptable, while if it falls outside that range, it is not acceptable. The Taguchi methodology suggests that instead of this implied step function of acceptability, a more realistic func tion is used based on the square of the deviation from the ideal target: in other words, any devi ation from a specified target performance causes substantial "loss."

This function, the quality loss function, is given by the expression

$$L = k(x - a)^2$$

where $L$ is the loss to society of a unit of output at value $x$; $a$ is the ideal state target value where, at $a$, $L = 0$; and $k$ is a constant.

While the form of the loss function may be regarded as being more realistic than a step function, the practicalities of determining the constant of $k$ with any degree of accuracy can be formidable. Moreover, even the shape of the function can be questioned because conse quences of variation are rarely symmetrical. These limitations may explain why most suc cessful applications of the Taguchi methodology are associated with relatively limited aspects of design (e.g., single parts) rather than very com plex products or services.

See also *design; design for manufacture; quality management systems; statistical quality tech niques*

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## technology tiers

*Christer Karlsson*

A technology tier is a level in a product system: final product, system, subsystem, component, part. As a concept it contrasts with traditional categorizations of "vertical" technologies (i.e., specialized areas such as mechanics, electronics, materials, etc.). More and more companies are moving from selling discrete products to selling functions that create customer value; in other words, it is not just the product itself that is important, but also the product functionality and the associated brand, etc.

In order to be able to cope with correspond ingly more complex product offerings, firms are abandoning lower "levels" of technology and complex product development is increasingly dependent upon fewer and larger suppliers who provide "technology systems solutions": e.g., a braking system in the automotive sector. The DIVISION OF LABOR between the original equipment manufacturer (OEM) and its subcon tractors and suppliers is hence increasingly based on the idea of technology levels or tiers. Suppliers take care of technical specialization, while further development of product functions takes place within the OEM. This means that the OEM manufacturer specializes in concept devel opment and integration of technical functions. Specialist technical fields, however, become the domain of big and more technically proficient suppliers. This is a possibility but also becomes a risk. So called "mega suppliers" can achieve temporary monopolies.

See also *design chain; new product development process; product architecture; product design pro cess; product modularity*

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## teleworking

*Alan Betts*

Teleworking is the ability to work from home using telecommunications and/or computer technology. Its rise in popularity is due partly to changes in the sectoral balance of employ ment. The service sector in most developed economies now accounts for between 70 and 80 percent of all employment. Even within the manufacturing sector, the proportion of people with indirect jobs (those not directly engaged in making products) has also increased signifi cantly. One result of this is an increase in the number of jobs that are not "location specific." Many jobs could be performed at any location where there are communication links to the rest of the organization. The other influence on the popularity of teleworking is the increasing power of communications technology.

Teleworking is also known as using "alterna tive workplaces" (AW), "flexible working," "home working" (that is generally considered to be a misleadingly narrow term), and creating the "virtual office."

Not everyone who has the opportunity to telework will require, or even want, the same degree of separation from their work office. Davenport and Pearlson (1998) have identified five stages on a continuum of alternative work arrangements:

- *Occasional telecommuting*: This is probably still the most common form, where people have fixed offices but occasionally work at home. Information technology workers, aca demics, and designers may work in this way.
- "*Hoteling*": This is an arrangement where individuals often visit the office, yet, because they are not always present, they do not require fixed office space. Rather, they can reserve an office cubicle ("hotel room") in which they can work. Professional service staff, such as consultants, may use this ap proach.
- *Home working*: Probably have no office as such (although they may "hotel" occasion ally) but they may have a small office or office space at home. Much of their work may be performed on the Internet or tele phone. For example, customer service workers or telemarketing personnel could fall into this category.
- *Fully mobile*: At the extreme level, staff may not even have home offices. Instead they spend their time with customers or sup pliers, or traveling between them. They rely on mobile communications technology. Field sales staff and customer service staff may fall into this category.

The degree of communications technology re quired varies with different degrees of telework ing. Occasional telecommuting needs only a simple email connection. But, as the technology demands of teleworking increase, so the space requirements of staff decrease. Indeed, much of the justification for teleworking is based on the (sometimes dramatically) reduced level of office space required.

However there may be a difference between what is technically possible and what is organ izationally feasible. None of the types of tele working is without its problems. In particular, those types that deny individuals the chance to meet with colleagues often face difficulties. Problems can include the following:

- *Lack of socialization*: Offices are social places where people can adopt the culture of an organization as well as learn from one an other. It is naive to think that all knowledge can be codified and learned formally at a distance.
- *Effectiveness of communication*: A large part of the essential communication we have with our colleagues is unplanned and face to face. It happens on "chance meet" occasions, yet it is important in spreading contextual information as well as establishing specific pieces of information necessary to the job.
- *Problem solving*: It is still often more efficient and effective informally to ask a colleague for

help in resolving problems than formally to frame a request using communications technology.

- *It is lonely*: Isolation amongst teleworkers is a real problem. For many of us, the workplace provides the main focus for social interaction. A computer screen is no substitute.

See also *division of labor; empowerment; group working; job design; job enlargement; job enrichment; job rotation; method study; work organization*

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### time-based performance

*Nigel Slack*

In an increasingly competitive world, operational "speed" or the time taken to deliver products or services is increasingly viewed as a core operations objective (*see* OPERATIONS OBJECTIVES). Time based performance manifests itself in two principal (and related) aspects of operations performance:

1 The *time to process an order and then produce/deliver* the product or service. Given that speed is intimately linked with throughput and therefore work in progress, many LEAN PRODUCTION initiatives have sought to, for example, reduce setup times (*see* SETUP REDUCTION), overcome bottleneck effects (*see* BOTTLENECKS), and minimize variability.

2 The *time taken to develop new products or services* from concept through to the point where they become available to customers (often referred to as TIME TO MARKET).

#### Customer Benefits of Speed

The most obvious benefit of speedy operations is that customers receive their good or services faster. In some competitive circumstances reduced delivery lead times can be vital; in others it is less important, though rarely totally unimportant. Speed is seen as giving direct competitive benefits, including the potential to command a premium price, developing long term relationships based on responsiveness to delivery changes, or extending product or service range. In addition, fast response can minimize some of the effects of the supply chain amplification of demand fluctuations (*see* SUPPLY CHAIN DYNAMICS).

#### The Internal Benefits of Speed

From an operations management (OM) perspective the main interest in speed is that it can result in benefits within the operation. In this sense "speed" is used to refer to the time taken for the transformed resources of the operation to move through the sequence of processes that effect their transformation; this is usually known as the throughput time for the operation. Specific internal benefits include the following:

- Speed reduces speculative activity. Reducing throughput time prior to finished goods stocks (if used) reduces the proportion (and often the absolute amount) of speculative activity in the operation. The production of goods prior to a specific customer order being placed for them is always to some extent speculative and carries the risk of the effort put into their production being wasted. An operation with long throughput times would need to start production (and hence speculation) considerably in advance of the products being required.
- Speed allows better forecasts, not only by providing some protection against poor forecasts but in making better forecasts more likely. Events well in the future are more difficult to forecast than imminent events and forecast error is directly proportional to how far ahead is the event being forecast (*see* FORECASTING PROCESS).
- Speed reduces overheads, or at least provides the potential to do so. The longer an order or a batch spends in the operation, the more overheads it attracts. An order that moves quickly through the operation takes less "looking after" than one that lingers. It needs less heating, lighting, and space, it

does not need as much controlling, checking, and monitoring.

- Speed lowers work in progress. When material passes quickly through the operation it cannot spend as much time in the form of work in progress, waiting to be processed. The time that material or information takes to move through the operation is either taken in being processed, traveling between processing stages, or waiting to be processed. Waiting time is by far the largest element in the throughput cycle and is seen as the obvious part to be reduced.
- Speed exposes problems and helps to reduce intrinsic inefficiencies in an operation. This is largely because stocks, either of materials or information, have the effect of obscuring problems in the operation. With work stored about the operation it becomes difficult to "see" the processes themselves. Problems are hidden and improvements smothered (*see* JUST IN TIME).

It is generally agreed that in most industries the potential for reducing throughput time is very great. The usual measure of internal speed is throughput efficiency (TE), the ratio of the total processing time for a batch of products to the total throughput time for the batch. Because in most traditionally organized manufacturing operations materials spend much of their time waiting to be processed, TE is usually very low, typically between 5 and 0.05 percent.

The attention of both academics and practitioners has increasingly focused on how throughput time may be shortened. Several prescriptions have been proposed which either identify the sources of potential improvement or change the way processing is organized so as to minimize delays. There are several "mapping" techniques that follow the route of materials, customers, or information. They usually try to distinguish between the "real time" where some value is being added by a process, and those times which are "non value added." In essence most mapping techniques are similar to process charts (*see* PROCESS MAPPING) but used at a more macro level of analysis. The types of activity that may be considered non value adding will depend on the type of operation being mapped. Yet whatever activities are classed as non value added, it is they that can be simplified, merged, or eliminated in order to shorten throughput times without detracting from the value adding activities. There is also common agreement that operations can gain benefit from BENCHMARKING their time based measurements of performance against other similar operations.

A related approach concentrates on methods of avoiding delays. Decision making delays, especially, seem to be cited as worthy of attention. This involves identifying the number of formal decisions needed during the throughput cycle. Some decisions may be eliminated, while others may be made by exception and, where decisions are necessary, they may be made by the lowest competent authority.

See also *build to order; delivery dependability; flexibility; life cycle effects; Little's Law*

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**time study**

*John Heap*

Time study is a structured process of directly observing and measuring (using a timing device) human work in order to establish the time required for completion of the work by a qualified worker when working at a defined level of performance. It follows the basic procedure of WORK MEASUREMENT of analysis, measurement, and synthesis. The observer undertakes preliminary observation of the work (a pilot study) to identify suitable elements that can be clearly recognized on subsequent occasions and are convenient, in terms of their length, for measurement. Subsequent studies are taken during which the observer times each occur rence of each element (using a stopwatch or other timing device) whilst at the same time making an assessment of the worker's rate of working on an agreed rating scale. (One of the prime reasons for measuring elements of work, rather than the work as a whole, is to facilitate the process of rating. The rate at which a worker works will vary over time; if elements are care fully selected, the rate of working should be consistent for the relatively short duration of the element.) This assessment of rating is used to convert the observed time for the element into a basic time – a process referred to as "exten sion." It is essential that a time study observer has been properly trained in the technique and especially in rating. The technique, when prop erly undertaken, involves the use of specific con trol mechanisms to insure that timing errors are within acceptable limits. Increasingly, timing is by electronic devices rather than by mechanical stopwatch; some of these devices also assist in subsequent stages of the study by carrying out the process of "extending" or converting ob served times into basic times.

The number of cycles that should be observed depends on the variability in the work and the level of accuracy required. Since time study is essentially a sampling technique in which the value of the time required for the job is based on the observed times for a sample of observations, it is possible using statistical tech niques to estimate the number of observations required under specific conditions. This total number of observations should be taken over a range of conditions (where these are variable) and, where possible, on a range of workers. Once a basic time for each element has been determined, allowances are added to derive a standard time.

Time study is a very flexible technique, suit able for a wide range of work performed under a wide range of conditions, although it is difficult to time jobs with very short cycle times (of a few seconds). Because it is a direct observation tech nique, it takes account of specific and special conditions, but it does rely on the use of the subjective process of rating. However, if prop erly carried out, it produces consistent results and is widely used. Additionally, the use of elec tronic data capture and personal computers for analysis makes it much more cost effective than previously.

See also *analytical estimating; predetermined motion time systems; work study; work time distri butions*

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## time to market

*Chris Voss*

When defined formally, "time to market" is the elapsed time between the inception of a product or service idea, definition, concept, etc. and its availability on the market introduction. More fundamentally, the widespread adoption of the metric actually reflects many firms' concern with reducing the time to market of their prod ucts and services. Being faster to market can underpin a greater market share and price real ization. As Wheelwright and Clark (1992) indi cate, "a six month jump on competitors in a market accustomed to eighteen to twenty four month design lives can translate into as much as three times the profit over the market life of the design. Conversely, being late to market with a new product can lead to break even results and zero profit." Thus, over the long term, a signifi cant performance gap can appear between a fast cycle and slow cycle competitor. For example, it has been estimated that in the elec tronics industry, introducing a product nine to 12 months late can cost it 50 percent of its potential revenues. A long development process exposes the project to the risk of changes in the market and environment. Especially when product life cycles are short, product modifications and re placements need to be managed more effectively if market share and profits are not to be lost.

Many broader benefits can also be realized from reducing time to market (Stalk and Hout, 1990). Firms may become technological leaders – actual and perceived by the customer – sup ported through being able to incorporate the latest technology into the product closer to the time of market introduction. Being fast to market can establish the product or service as the market standard, an issue of critical signifi cance for many interconnection technologies (e.g., mobile phones). This can lead to a higher price realization, as the product or service be comes sought after by customers. Similarly, cus tomer relations can improve as companies gain flexibility to respond quickly to a changing mar ketplace. Finally, reduced time can lead to re duced costs: total development costs can be lowered because early exchange of information and resolution of conflicts result in the need for fewer engineering changes and review proced ures; inventory levels can be minimized; and overhead costs – such as reduced breakdown costs, delays, and number of working hours – can be reduced.

See also *time based performance*

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## total productive maintenance

*Michael Shulver*

Total productive maintenance (TPM) is pro ductive maintenance carried out by all employ ees through small group activities. In this respect it can be considered analogous to TOTAL QUALITY MANAGEMENT programs: for example, the dual goal of TPM is zero break downs and zero defects. When breakdowns and defects are eliminated, equipment operation rates improve, costs are reduced, spare parts inventory can be minimized, and, as a conse quence, overall PRODUCTIVITY increases.

TPM works to eliminate what are termed the "six big losses" that are regarded as formidable obstacles to equipment effectiveness. They are:

- *Downtime*: (1) equipment failure from break downs; (2) setup and adjustment from ex change of dies in injection molding machines, etc.
- *Speed losses*: (3) idling and minor stoppages due to the abnormal operation of sensors, blockage of work on chutes, etc.; (4) reduced speed due to discrepancies between designed and actual speed of equipment.
- *Defects*: (5) process defects due to scraps and quality defects to be repaired; (6) reduced yield from machine start up to stable pro duction.

It has been reported that typically, within three years from the introduction of TPM, companies show 15–25 percent increases in equipment op eration rates while others show a 90 percent reduction in process defects. Labor productivity is generally increased by 40–50 percent.

In the years following World War II the Jap anese industrial sectors imported PREVENTIVE MAINTENANCE (PM) from the US. Preventive maintenance was introduced in the 1950s and remained well established until the 1970s. Japan's PM consisted mainly of time based maintenance featuring periodic servicing and overhaul. During the 1980s PM was rapidly being replaced by predictive maintenance, or CONDITION BASED MAINTENANCE.

TPM is often defined as productive mainten ance involving total participation. Frequently, management misconstrues this to imply that only shop floor staff need be involved. However, TPM should be implemented on a company wide basis. TPM aims to establish good main tenance practice in operations through the pur suit of "the five goals of TPM," as follows:

1 *Improve equipment effectiveness*: Examine how the facilities are contributing to the effectiveness of the operation by examining all the losses that occur. Loss of effectiveness can be the result of downtime losses, speed losses, or defect losses.
2 *Achieve autonomous maintenance*: Allow the people who operate or use the operation's equipment to take responsibility for at least some of the maintenance tasks. Also encourage maintenance staff to take responsibility for the improvement of maintenance performance. There are three stages in which staff take responsibility for maintenance: (a) the repair level, where staff carry out instructions but do not predict the future, they simply react to problems; (b) the prevention level, where staff can predict the future by foreseeing problems and taking corrective action; and (c) the improvement level, where staff can predict the future by foreseeing problems, and not only take corrective action but also propose improvements to prevent recurrence.
3 *Plan maintenance*: Have a fully worked out approach to all maintenance activities. This should include the level of preventive maintenance that is required for each piece of equipment, the standards for condition based maintenance, and the respective responsibilities of operating staff and maintenance staff. The respective roles of operating and maintenance staff are seen as being distinct. Maintenance staff are seen as developing preventive actions and general breakdown services, whereas operating staff take on the "ownership" of the facilities and their general care. Similarly, the respective responsibilities of the two types of staff are seen as distinct. Maintenance staff are held to be responsible for the training of operators, problem diagnosis, and devising and assessing maintenance practice.
4 *Train all staff in relevant maintenance skills*: The responsibilities of operating and maintenance staff require that both have all the skills to carry out their roles. TPM places a heavy emphasis on appropriate and continuous training.
5 *Achieve early equipment management*: This goal is directed at going some way toward avoiding maintenance altogether by "maintenance prevention" (MP). MP involves considering failure causes and the maintainability of equipment during its design stage, its manufacture, its installation, and its commissioning. In this way, TPM attempts to trace all potential maintenance problems back to their root cause and then tries to eliminate them at that point.

The first principal feature of TPM, total effectiveness or profitable PM, is also emphasized in predictive and productive maintenance. The second feature, a total maintenance system, is another concept first introduced during the productive maintenance era. It establishes a maintenance plan for the equipment's entire lifespan and includes maintenance prevention (MP: maintenance free design), which is pursued during the equipment design stages. Once equipment is assembled, a total maintenance system requires preventive maintenance and maintainability improvement (MI: repairing or modifying equipment to prevent breakdowns and facilitate ease of maintenance). The last feature, autonomous maintenance by operators (small group activities), is unique to TPM.

See also *failure analysis; maintenance; reliability centered maintenance*

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## total quality management

*Barrie Dale*

There are many interpretations and definitions of total quality management (TQM). Put simply, TQM is the mutual cooperation of everyone in an organization and associated business processes to produce value for money products and services that meet and hopefully exceed the needs and expectations of customers.

TQM is both a philosophy and a set of guiding principles for managing an organization to the benefit of all stakeholders. The eight quality management principles are defined in BS EN ISO 9000 (2000) as:

- *Customer focus*: Organizations depend on their customers and therefore should understand current and future customer needs, should meet customer requirements, and strive to exceed customer expectations.
- *Leadership*: Leaders establish unity of purpose and direction of the organization. They should create and maintain the internal environment in which people can become fully involved in achieving the organization's objectives.
- *Involvement of people*: People at all levels are the essence of an organization and their full involvement enables their abilities to be used for the organization's benefit.
- *Process approach*: A desired result is achieved more efficiently when activities and related resources are managed as a process.
- *System approach to management*: Identifying, understanding, and managing interrelated processes as a system contributes to the organization's effectiveness and efficiency in achieving its objective.
- *Continual improvement*: Continual improvement of the organization's overall performance should be a permanent objective of the organization.
- *Factual approach to decision making*: Effective decisions are based on the analysis of data and information.
- *Mutually beneficial supplier relationships*: An organization and its suppliers are interdependent and a mutually beneficial relationship enhances the ability of both to create value.

Despite the divergence of views on what constitutes TQM, there are a number of key elements in the various definitions that are now summarized.

### Commitment and Leadership of the Chief Executive Officer

Without the total demonstrated commitment of the chief executive officer (CEO) and his/her immediate executives and other senior managers, nothing much will happen and anything that does will not be permanent. They have to take charge personally, lead the process, provide direction, exercise forceful leadership, including dealing with those employees who block improvement, and maintain the impetus. However, whilst some specific actions are required to give TQM a focus, as quickly as possible it must be seen as the style of management and the natural way of operating a business.

### Planning and Organization

This features in a number of facets of the improvement process and includes the following:

- Developing a clear long term strategy for TQM, which is integrated with other strategies such as information technology, production/operations and human resources, and also with the business plans of the organization (*see* MANUFACTURING STRATEGY; OPERATIONS STRATEGY; SERVICE STRATEGY).
- Deployment of the policies through all stages of the organizational hierarchy with objectives, targets, projects, and resources agreed with those responsible for insuring that the policies are turned from words into actions.
- Building product and SERVICE QUALITY into designs and processes.
- Developing prevention based activities (e.g., mistake proofing devices) (*see* FAIL SAFING).
- Putting quality assurance procedures into place that facilitate closed loop corrective action.
- Planning the approach to be taken to the effective use of QUALITY MANAGEMENT SYSTEMS, procedures, and tools and techniques (*see* QUALITY TOOLS) in the context of the overall strategy.
- Developing the organization and infrastructure to support the improvement activities; this includes allocating the necessary re

sources to support them. Whilst it is recommended to set up some form of steering type activity to provide direction and support and make people responsible for coordinating and facilitating improvement, the infrastructure should not be seen as separate from the management structure.

- Pursuing standardization, systematization, and simplification of work instructions, procedures, and systems.

### Using Tools and Techniques

To support and develop a process of CONTINUOUS IMPROVEMENT, an organization will need to use a selection of tools and techniques within a problem solving approach. Without the effective employment and mix of tools and techniques it will be difficult to solve problems. The tools and techniques should be used to facilitate improvement and be integrated into the routine operation of the business. The organization should develop a route map for the tools and techniques which it intends to apply. The use of tools and techniques helps to get the process of improvement started; employees using them feel involved and that they are making a contribution; quality awareness is enhanced and behavior and attitude change starts to happen; and projects are brought to a satisfactory conclusion.

### Education and Training

Employees, from the top to the bottom of an organization, should be provided with the right level and standard of education and training to insure that their general awareness and understanding of quality management concepts, skills, competencies, and attitudes are appropriate and suited to the continuous improvement philosophy. Education and training also provide a common language throughout the business.

A formal program of education and training needs to be planned and provided on a timely and regular basis to enable people to cope with increasingly complex problems. It should suit the operational conditions of the business, i.e., training may be done in a cascade mode (everyone is given the same basic training within a set time frame) or, if appropriate, in an infusion mode (training is provided on a gradual progression basis to functions and departments on a need to know basis). This program should be viewed as an investment in developing the ability and knowledge of people and helping them realize their potential. Without training, it is difficult to solve problems, and without education, behavior and attitude change will not take place. The training program must also focus on helping managers think through what improvements are achievable in their areas of responsibility.

It also has to be recognized that not all employees will have received and acquired adequate levels of education. The structure of the training program may incorporate some updating of basic educational skills in numeracy and literacy, but it must promote continuing education and self development. In this way, the latent potential of many employees will be released and the best use of every person's ability achieved.

### Involvement

There must be a commitment and structure to the development of employees, with recognition that they are an asset that appreciates over time. All available means from suggestion schemes to various forms of teamwork must be considered for achieving broad employee interest, participation, and contribution in the improvement process. Management must also be prepared to share information and some of their powers and responsibilities and to loosen their reins. This involves seeking and listening carefully to the views of employees and acting upon their suggestions.

Part of the approach to TQM is to insure that everyone has a clear understanding of what is required of them, how their processes relate to the business as a whole, and how their internal customers are dependent upon them (*see* INTERNAL CUSTOMER–SUPPLIER RELATIONSHIPS). The more people understand the business and what is going on around them, the greater the role they can play in the improvement process. People have got to be encouraged to control, manage, and improve the processes that are within their sphere of responsibility.

### Teamwork

Teamwork needs to be practiced in a number of forms (*see* GROUP WORKING; QUALITY TEAMS). Consideration needs to be given to the operating characteristics of the teams employed, how they fit into the organizational structure, and the roles of member, team leader, sponsor, and facilitator. Teamwork is one of the key features of involvement and without it, dif ficulty will be found in gaining the commitment and participation of people throughout the or ganization. It is also a means of maximizing the output and value of individuals.

There is also a need to recognize positive performance and achievement and celebrate and reward success. People must see the results of their activities and that the improvements they have made really do count. This needs to be constantly encouraged through active and open communication. If TQM is to be success ful, it is essential that communication be effect ive and widespread. Sometimes managers are good talkers but poor communicators.

### Measurement and Feedback

Measurement, from a baseline, needs to be made continually against a series of key results indica tors – internal and external – in order to provide encouragement that things are getting better (i.e., fact rather than opinion). External indica tors are the most important as they relate to customer perceptions of product and/or service improvement. The indicators should be de veloped from existing business measures, from external (competitive, functional, and generic) and internal BENCHMARKING, and from cus tomer surveys and other means of external input. This enables progress and feedback to be clearly assessed against a roadmap or checkpoints. From these measurements, action plans must be de veloped to meet objectives and bridge gaps.

### Insuring that the Culture is Conducive to Continuous Improvement Activity

It is necessary to create an organizational culture that is conducive to continuous improvement and in which everyone can participate. Quality assurance also needs to be integrated into all an organization's processes and functions. This re quires changing people's behavior, attitudes, and working practices in a number of ways.

### TQM Approaches

There are a number of approaches that can be followed in the introduction of TQM. These include:

- a listing of TQM principles and practices in the form of a generic plan along with a set of guidelines;
- prescriptive step by step approaches;
- methods outlining the wisdom, philoso phies, and recommendations of the inter nationally respected experts on the subject (i.e., CROSBY, DEMING, FEIGENBAUM, and JURAN);
- self assessment methods such as the Mal colm Baldrige National Quality Award Model for Performance Excellence and the European Foundation for Quality Manage ment Excellence Model (*see* BUSINESS EX CELLENCE MODEL; SELF ASSESSMENT AND QUALITY AWARDS).
- non prescriptive methods in the form of a framework or model.

However, it is up to the management team of each organization to identify the approach that best suits their needs and business oper ation. Indeed, it is not unusual for an organiza tion to find that its TQM approach is not working out as planned and switch to another approach.

See also *quality; quality characteristics; quality costing*

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## trade-offs

*Nigel Slack*

Trade off theory is concerned with the manner in which OPERATIONS OBJECTIVES relate to one another. The assumptions made about these relationships are important because they influence the strategic expectations that the organization should have regarding the performance of its operations function and the expectations that the operations function should have regarding its own potential to improve operations performance.

The idea of trade offs in operations can sometimes be confusing because there are several similar terms used to describe ideas that are close to that of the trade off. Indeed, the different views of trade offs reflect a wider debate in business strategy concerning the extent to which businesses as a whole can achieve multiple strategic goals. Furthermore, there is no universally accepted distinction between terms such as trade off, dilemma, and paradox. However, there are differences in how the terms are used by writers on strategy.

A *paradox* is where two statements or descriptions of a problem are, or seem to be, mutually exclusive and yet each could be taken as "truth." There is no implication that any choice need be made between the two contradicting statements. Both operate simultaneously and are accepted as "true" even though they are mutually exclusive. By definition, a paradox cannot be solved. A choice need not be made. Paradoxes are sometimes related to *divergent problems*. These are

> Problems that are not easily quantifiable or verifiable and that do not seem to have a single solution. The more rigorously and precisely they are studied, the more the solutions tend to diverge, or to become contradictory and opposite. For example, the problem of world peace seems to necessitate security and protection on the one hand, and reducing the threat of war by disarmament on the other. The education of children is a process of passing on past knowledge and culture . . . as well as a process of allowing freedom, autonomy, and self-development. (Quinn, 1992)

Thus a paradox is something we have to live with rather than solve, yet at the same time it informs our decision making processes.

A *dilemma* is a less disturbing and difficult concept to understand. A dilemma is where two or more aims seem to be contradictory and yet can (perhaps with difficulty) be reconciled. In fact, "dilemma theory" suggests that managers are not constantly making heroic decisions between alternative courses of action; rather, they are constantly engaged in the process of reconciling seeming opposites. Usually dilemmas are stated as conflicts between broad aims rather than specific performance objectives. So, for example, there is a dilemma in choosing between organizational differentiation and integration, or between closeness to suppliers and the ability to strike a hard deal.

A *trade off* is a more operational concept. A trade off implies that there is a relationship between simultaneously desirable operations objectives. Furthermore, it implies that at least the broad form of this relationship is known. Originally, trade offs were seen as relationships that were largely fixed and immutable. More recently, trade offs have been depicted as relationships between performance objectives that hold true for a given set of technological, organizational, and attitudinal factors. By changing the nature of operations resources, so the nature of the trade off relationship may also be changed.

The basis of the trade off paradigm is that the improvement in one aspect of operations performance, to some degree, necessarily implies a reduction in some other aspect of performance. Put another way, it must consider trading off one aspect of performance with another. Taken to its extreme, the trade off paradigm implies that improvement in one aspect of an operation's performance *can only* be gained at the expense of performance in another. "There is no such thing as a free lunch" is often quoted as a summary of the trade off theory.

Probably the best known summary of the trade off idea comes from Skinner (1969), the most influential of the originators of the strategic approach to operations:

> most managers will readily admit that there are compromises or trade-offs to be made in designing an airplane or truck. In the case of an airplane, trade-offs would involve matters such as cruising speed, take-off and landing distances, initial cost, maintenance, fuel consumption, passenger comfort and cargo or passenger capacity. For instance no one today can design a 500-passenger plane that can land on an aircraft carrier and also break the sound barrier. Much the same thing is true in manufacturing.

Skinner's view was that all operations are, in effect, technically constrained systems. They have the potential to excel in a limited number (one or two) of operations objectives but can not be equally good at everything. Therefore, to realize their potential as a positive force, oper ations must focus on those objectives that best support the organization's competitive strategy (*see* FOCUS; OPERATIONS ROLE). This implies that a major task of operations managers is to determine the most appropriate operations ob jectives contingent upon competitive strategy.

The relevance of the trade off paradigm has been challenged by more evangelical approaches, most notably the "world class manufacturing" (WCM) movement (Schonberger, 1986), which takes a clear anti trade off stance. It holds that operations can indeed excel at many different objectives simultaneously.

The underlying philosophy of WCM is im provement oriented and radical when compared with the more conservative trade off paradigm. One way of characterizing the difference be tween the two approaches is by visualizing a lever, pivoted in the middle and free to move one end up at the expense of the other end going down, but also with the pivot able to move up and down. The height of each end is then analo gous to the level of performance achieved by the operations objectives that they represent. In terms of this "lever" model, there are two ways to improve the position of one end of the lever. One is to depress the other end, thereby improv ing one aspect of performance at the expense of another. The other way is to raise the pivot of the lever. This would raise one end of the lever without depressing the other end, or alterna tively, it could raise both ends. The "pivot" in a real operation represents the set of constraints that prevent both aspects of performance being improved simultaneously. These may be tech nical, or attitudinal, but the "pivot" is stopping one aspect of performance improving without it reducing the performance of another. Overcom ing these constraints is seen as the main im provement task by proponents of the WCM approach.

Two compromises have been suggested that attempt to bridge the gap between trade off and WCM approaches. One (New, 1992) distin guishes between different trade offs. Some trade offs, it is argued, do indeed appear to have been overcome by a combination of tech nological advances and alternative methods of organizing operations management. Most notably, the relationship between delivery speed and DELIVERY DEPENDABILITY, prod uct or service specification and specification consistency, or specification consistency and cost, do not necessarily trade off against each other. However, others, most notably specifica tion and cost, product or service range and deliv ery speed, product or service range and cost, and to some extent delivery speed and volume flexi bility, do exhibit a trade off relationship.

The other compromise (Slack, 1992) sees the trade off paradigm as being appropriate under some, but not all, circumstances. The time scale of any change in the relative performance levels of objectives is held to be especially important. In the short term the trade off paradigm corres ponds closely with observed system behavior. So an operation that was required to increase the range of its products or services would, in the very short term, have little choice but to suffer increased costs for doing so. However, if the same operation is allowed a longer period to reshape its resources with the specific goal of achieving an extended range of offerings, the probability of its doing so without the same increase in costs is greatly increased. Thus long term changes have at least the potential to overcome trade off relationships.

More recent authors hold that "trading off" by repositioning the balance between objectives and "overcoming trade offs" are, in fact, distinct strategies, either of which may be adopted at different times by organizations. Neither are they mutually exclusive; operations may choose to trade off by repositioning the balance of their performance both as a response to changes in competitive strategy and to provide a better starting point for improvement. Key to overcoming trade off constraints is the building of appropriate operating capabilities. Thus operations performance improvement is achieved by overcoming trade offs, which, in turn, is achieved through enhanced operations capabilities.

See also *operations strategy; order winners and qualifiers*

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## transformation model

*Nigel Slack*

Operations produce goods and services by coordinating "input" resources and deploying them to either "transform" other resources (or be transformed themselves), thereby creating "outputs" of goods and/or services. This open systems theory derived construct (see figure 1) is commonly used to describe, at a suitably generic level, the transformative nature of all operations, regardless of whether it is manufacturing operations producing tangible goods or SERVICE OPERATIONS producing intangible outputs.

### Inputs to the Transformation Process

The inputs to an operation can be classified as either transformed resources (the resources that are treated, transformed, or converted in some way) and transforming resources (the resources that act upon the transformed resources). The transformed resources that operations coordinate are usually some mixture of materials, information, and customers, although one of these types is often dominant in an operation. There is less variation between different operations'

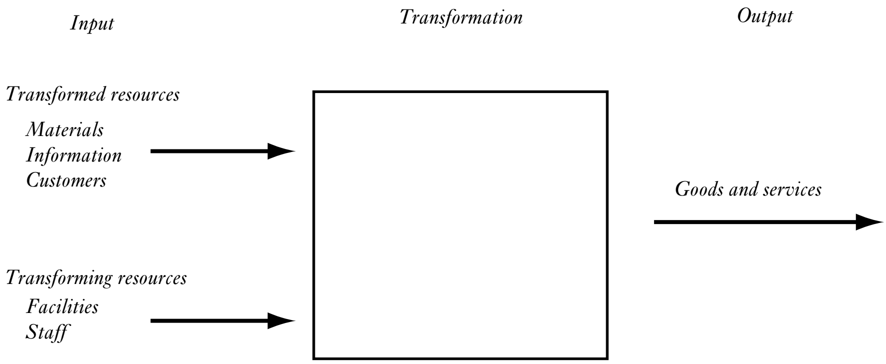


**Figure 1** The general transformation model

transforming resources. Two types of transforming resource are usually identified as forming the basic structure of all operations, namely, facilities, which are the buildings, equipment, plant, and PROCESS TECHNOLOGY of the operation, and staff, who operate, maintain, plan, and manage the operation. Also, sometimes included as transforming resources are consumable items which, although strictly material resources, are not the main subject of transformation, only incidental to it.

### The Transformation Process

Manufacturing operations comprise transformation processes that transform the physical properties of materials. LOGISTICS operations comprise processes that change the location of materials. Retail operations change the possession or ownership status of the materials. Accountants process information in a way that alters the form of the information. Some operations, such as libraries, store or accommodate the information, while others change the location of the information, such as telecommunication companies.

Operations that process customers might change their physical properties in a similar way to material processors, as do hairdressers and cosmetic surgeons. Some store or accommodate them (hotels, for example). Airlines, mass rapid transport systems, and bus companies transform the location of their customers, while some transform the physiological state of their customers, such as hospitals. Others transform the psychological state of their customers, for example most entertainment services.

### Outputs from the Transformation Process

The outputs from (and purpose of) the transformation process are goods and services, which are generally seen as being different. Most operations produce a mixture of goods and services and can be positioned on a continuum from "pure" goods producers to "pure" service producers. Some extraction companies are concerned almost exclusively with their product. Other "commodity like" goods producers, such as steel makers, are again largely concerned with the production of products, although they might also produce some services such as technical advice. Capital goods manufacturers are similar in so far as they primarily produce goods, but to an even greater extent they also produce facilitating services such as technical advice, applications engineering services, installation, maintenance, and training. However, the services produced by restaurants are an important part of the operation's output. A computer services firm might also produce software "products" but is primarily providing a service to its customers. Further along the continuum a management consultancy, although producing reports and documents, is a service provider that uses facilitating goods. Finally, some pure services do not produce products at all, for example, a psychotherapy clinic that provides therapeutic treatment for its customers without any facilitating goods.

See also *hierarchy of operations; operations activities; operations management; product–service systems*

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## TRIZ

*James Moultrie*

TRIZ, or the "theory of inventive problem solving," was developed by the Russian Genrich

Altshuller in 1946, following an analysis of over 400,000 patents. Altshuller discovered that many technical problems contain a fundamental conflict, which can be solved by the application of one of only a few hundred "inventive prin ciples." These principles now form the basis for a suite of creativity tools.

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# V

**value engineering**

*Nigel Slack*

Value engineering is a technical process whereby product designs are modified in order to minim ize costs that do not contribute to the value and performance of the product. The process is usu ally "applied" to products prior to their manu facture (compared with "value analysis," which is a similar process applied to products currently being manufactured). The origins of the ap proach are credited to the General Electric Com pany, which engaged in a systematic study during World War II to investigate alternative materials, designs, and production processes in order to maintain production levels. The com pany found that in most cases the alternative materials and processes performed at least as well and often better in terms of both specifica tion and cost. This led it to formalize its proced ures for analyzing the value of each part and product. Value is the primary concept whereas previous "design to cost" approaches had as sumed a trade off between product features that could be manipulated to achieve a required cost (*see* TRADE OFFS).

Different types of value are recognized by the approach. "Use value" is the cost to the user of the attributes of a product that enable it to per form its function. "Cost value" is the total cost of producing the product. "Esteem value" is the additional cost that a product can attract because of its intrinsic attractiveness to purchasers. "Ex change value" is the sum of the attributes that enable the product to be exchanged or sold. Although the relative magnitude of these differ ent types of value will vary between products, and also probably over the life of a product, the value approach attempts to identify the contri bution of each feature to each type of value through systematic analysis and structured creativity enhancing techniques.

Value engineering programs are usually con ducted by project teams consisting of designers, purchasing specialists, operations managers, and financial analysts. PARETO ANALYSIS is often used to identify the parts of the total design package that are worthy of most attention. The chosen elements are then subject to rigorous scrutiny. The team analyzes the function and cost of those elements and tries to find any similar components that could do the same job at lower cost. For example, the team might at tempt to reduce the number of components, use cheaper materials, or simplify the processes.

See also *design; design for manufacture*

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**variety**

*Michael Lewis*

Variety is the term used to denote the range of different products or services an operation pro duces. A taxi company, for instance, offers a high variety service. It may confine its services to the transportation of people and their luggage, but it is prepared to pick you up from almost anywhere and drop you off almost anywhere. It may even take you by a route of your choice. In order to do this it must be relatively *flexible*. Drivers must have a good knowledge of the area, and communication between the base and the taxis must be effective.

The variety on offer by the service does allow it to match its services closely to its customers' needs. However, this does come at a price. The cost per kilometer traveled will be higher for a taxi than for a less customized form of transport such as a bus service. Although both serve, more or less, the same customers with the same needs by providing transport over relatively short dis tances (say, less than 20 km), the taxi service has, in theory, an infinite number of routes to offer its customers, while the bus service has a few well defined routes. The buses travel these routes according to a set schedule, published well in advance and adhered to in a routine manner. If all goes to schedule, little, if any, flexibility is required from the operation. All is standardized and regular. More significantly, the lack of change and disruption in the day to day running of the operation results in relatively low costs compared with using a taxi for the same journey.

As suggested in the above examples, a key factor in the significance of variety is that cost is highly variety sensitive. Any organization that manufactures only one product for only one customer at constant quantities would be very simple to manage. Production time lost in setups would be negligible, each step of the process would have matched capacities and be operated in synchronization, quality costs would be low, as would inventories. Management costs would be low because everything would be almost per fectly stable.

The introduction of even a single additional product (or service) changes all of this. It is difficult to maintain production of one product or service at a constant rate when demand for the others must also be satisfied. Production sched ules must be created and managed. Changeovers will require both SCHEDULING and manage ment as products and services compete for the same facilities. QUALITY could become more expensive, since with each changeover, the pro cess has to be brought into tolerance. Additional process steps are likely to be required. Because it is much more difficult to match the capacities of each step of the process, it is unlikely that pro cesses can be operated in unison. A greater var iety of purchased items will be needed (in what is now an irregular pattern) to meet the production schedules. Work in process inventories are expected to increase as inventories are built up to enable the many parts of the process to con tinue operating. Finished goods inventories will possibly increase because while one product is being manufactured, stocks of other products have to be maintained to satisfy demand. Cus tomer priorities must be weighed against the priorities for smooth operation of the factory; as a consequence, the process is rarely in balance.

The disadvantage of excessive variety explains the benefits of Skinner's (1974) concept of FOCUS, but many strategies have evolved in recent years to cope with the apparent paradox of consumer demands for greater product and service choice at lower and lower cost. For in stance, ports have always had to handle a huge variety of cargoes with widely different contents, sizes, and weights and, whilst in transit or in storage, protect them from weather and pilfer age. Then the transportation industries, in con junction with the International Standards Organization (ISO), developed a standard ship ping container design. Almost overnight the problems of security and weather protection were solved. Anyone wanting to ship goods in volume only had to seal them into a container and they could be signed over to the shipping company. Ports could standardize handling equipment and dispense with warehouses (con tainers could be stacked in the rain if required). Railways and trucking companies could develop trailers to accommodate the new containers.

See also *flexibility; planning and control in oper ations; process types; service processes; volume*

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## vendor-managed inventory

*Pietro Romano*

In vendor managed inventory (VMI) systems, the distributor or manufacturer monitors and manages inventories at the wholesaler or retailer. Thus, in the VMI process, rather than a cus tomer submitting orders, the vendor itself has responsibility for managing the replenishment of stock as needed. This is sometimes referred to as supplier managed inventory (SMI) or co managed inventory. VMI centralizes the replen ishment decision for all retailers at the upstream distributor or manufacturer. This practice existed in retailing before the growth of enabling technologies. Now, the existence of suitable in formation systems facilitates the implementation of VMI.

**vertical integration**

*Nigel Slack*

Vertical integration is the extent to which an organization owns the network of companies or processes that together give products or services their value. It involves an organization assessing the benefits of acquiring suppliers or customers. At a more micro level, it is the decision of whether to make a particular individual compon ent or to perform a particular service itself, or alternatively buy it in from a supplier (*see* MAKE OR BUY). At the strategic level, vertical integra tion is a topic more of interest to economists. However, operations managers are required to assess its practical effects. It is also included as an element of the content of manufacturing strategy by some authorities.

An organization's vertical integration strategy can be defined in terms of the following (Hayes and Wheelwright, 1984):

- the direction of vertical integration;
- the extent of the process span required;
- the balance among the resulting vertically integrated stages.

The strategy of expanding on the supply side of an organization's supply network is sometimes called backward or "upstream" vertical integra tion, and expanding on the demand side is sometimes called forward or "downstream" ver tical integration. Backward vertical integration through an organization taking control of its suppliers is sometimes used either to gain cost advantages or to prevent competitors gaining control of important suppliers. For this reason it is sometimes considered a strategically defen sive move. Forward vertical integration, on the other hand, takes an organization closer to its markets and allows more freedom for an organ ization to make contact directly with its custom ers. For this reason forward vertical integration is sometimes considered an offensive strategic move.

Having established its direction of expansion, an organization must then decide how far it wishes to take the extent of its vertical integra tion. Some organizations deliberately choose not to integrate far, if at all, from their original part of the supply chain. Alternatively, some organ izations choose to become very vertically inte grated.

The third dimension of vertical integration does not strictly concern the ownership of the supply chain; it concerns the capacity and, to some extent, the operating behavior of each stage in the chain that is owned by the organiza tion. The balance of the part of the chain owned by an organization is the amount of the capacity at each stage in the chain that is devoted to supplying the next stage. So a totally balanced relationship is one where one stage produces only for the next stage and totally satisfies its requirements. Less than full balance in the stages allows each stage to sell its output to other companies or to buy in some of its supplies from other companies.

Fully balanced networks have the virtue of simplicity and also allow each stage to focus on the requirements of the next stage along in the network. Having to supply other organizations, perhaps with slightly different requirements, might serve to distract from what is needed by their primary customer. However, a totally self sufficient network is sometimes not feasible.

See also *outsourcing; purchasing; supply chain management*

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## volume

*Michael Lewis*

Volume is the term used to denote the level of broadly similar products or customers an operation is required to process – or similar tasks it is required to perform – per unit of time. Volume related, together with variety related, characteristics are principle determinants of the nature of operations processes. Developed from an attempt to articulate the fit between tangible product life cycle characteristics and manufacturing process types (Abernathy and Utterback, 1975), the volume–variety matrix (see figure 1) offers a generic representation of the inverse relationship between production volume and task variety.

With particular reference to physical transformation PROCESS TECHNOLOGY, zone A operations – serving low volume and high variety markets – "naturally" require the FLEXIBILITY, and accept the higher operating costs per unit of capacity, delivered by small scale, loosely coupled technologies with extensive human intervention. Zone B operations – serving price sensitive, high volume, and low variety markets – "naturally" require the lower capital and operating costs per unit of capacity, and accept the greater capital expenditure and lower levels of flexibility, delivered by large scale, automated, and integrated solutions.

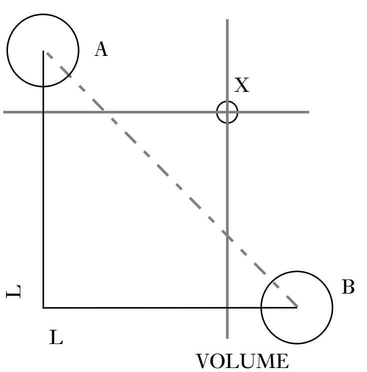


**Figure 1** The volume variety matrix

Consider the following example. McDonald's has become the epitome of high volume food (hamburger) production, serving millions of burgers around the world every day. Volume has important implications for the way McDonald's operations are organized. Look behind the counter and the first thing you notice is the *repeatability* of the tasks people are doing. Because tasks are repeated frequently, it makes sense to *specialize*: one person assigned to cooking the burgers, another assembling the buns, another serving, and so on. This leads to the *systemization* of the work where standard procedures are set down in a manual, with instructions on how each part of the job should be carried out. Also, because tasks are systematized and repeated, it is worthwhile developing specialized fryers and ovens. The most important implication of high volume, though, is that it gives *low unit costs*; the fixed costs of the operation, such as heating and rent, are spread over a large number of products or services.

Now contrast this with a small local cafeteria serving a few "short order" dishes. The range of items on the menu may be similar to the larger operation, but the volume will be far lower. Therefore the degree of repetition will also be far lower. Furthermore, the number of staff will be lower (possibly only one person), and therefore individual staff are likely to perform a wider range of tasks. This may be more rewarding for the staff, but less open to systemization. Fewer burgers cooked also makes it less feasible to invest in specialized equipment. For all of these reasons, it follows that the cost per burger served is likely to be higher (even if the price is comparable).

Finally, it is advisable to take care when applying the conventional generalization regarding high and low volume operations. For example, aircraft manufacture is relatively low volume compared with television manufacture. Yet much of the comments on high volume operations still apply to aircraft production. It is highly systematized, with specialized jobs, performed by employees who only undertake a small part of the total job. Aircraft at Boeing are even made on an assembly line basis (albeit a very slow one) like televisions. This seeming anomaly is partly due to the care taken in the construction of aircraft because of safety consid erations. Mainly, though, it is due to the amount of work that goes into each aircraft. The number of products made may be relatively low, but the number of staff hours that are devoted to a day's production is very high, as is the number of repetitions (the number of times a rivet is inserted and a cable is joined) each day.

See also *capacity management; job design; process types; service processes; variety*

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# W

## WITNESS simulation package

*Andrew Greasley*

WITNESS™ is a visual interactive modeling (VIM) system based on the discrete event simulation method (*see* SIMULATION MODELING). Elements are added to the WITNESS simulation by clicking on the required element in the designer element window and then clicking again at the required location in the simulation window. WITNESS is widely used by academic and industrial users.

For more information, consult the website: http://www.lanner.com.

See also *business process redesign; process mapping; queuing analysis; SIMUL8 simulation package*

## work breakdown structures

*Ralph Levene*

A work breakdown structure (WBS) is a systematic way of defining the scope of a project. The process can be defined formally as breaking down (or decomposing) the project into natural elements for management and control purposes. Effectively, this means creating "more manageable chunks of work." Carrying out the process of determining the WBS has immense value in helping to identify missing scope items and areas for further definition. Graphically, presentation is a pyramidal representation showing a hierarchical subdivision of the project, normally drawn similar to a family tree.

The structure and content of the WBS should be agreed by at least the key team members. Drawing the WBS is often a consensus group process, involving the relevant parties who will carry out the project. The WBS diagram and its structural detail provide the basis for responsibilities to be identified, relating elements of work to each other and to the end product (deliverable). It also provides the basis for the organization of work for subsequent integration and the planning and control system. Above all, it is an excellent visual way to communicate the scope of the project.

In breaking the project down to its component parts or products, any associated management services should be included to encompass the entire project. The elements of the lowest level of breakdown are generally called work packages. These must be unique and clearly distinguishable from one another. Constructing the WBS can be approached in a number of ways, the most common being: project life cycle, functional use, component or product, and geographical area. A view of these approaches shows the advantage of a diagrammatic representation (see figure 1).

The breakdown shows the work to be done, and associated with each work package will be products or deliverables. The work packages then form the basis for control and are defined further by a description of the work to be performed as part of the package, which is responsible for its delivery, and a budget and time frame for completing the work. Although the product or component form is most commonly used, a WBS is often of a mixed approach, e.g., the top levels may be phase oriented and the lower levels product or function oriented.

A number of factors influence how the WBS is created, i.e., the type of project (life cycle for software projects), the use of organizational standards, and the preferences of the project manager and team.

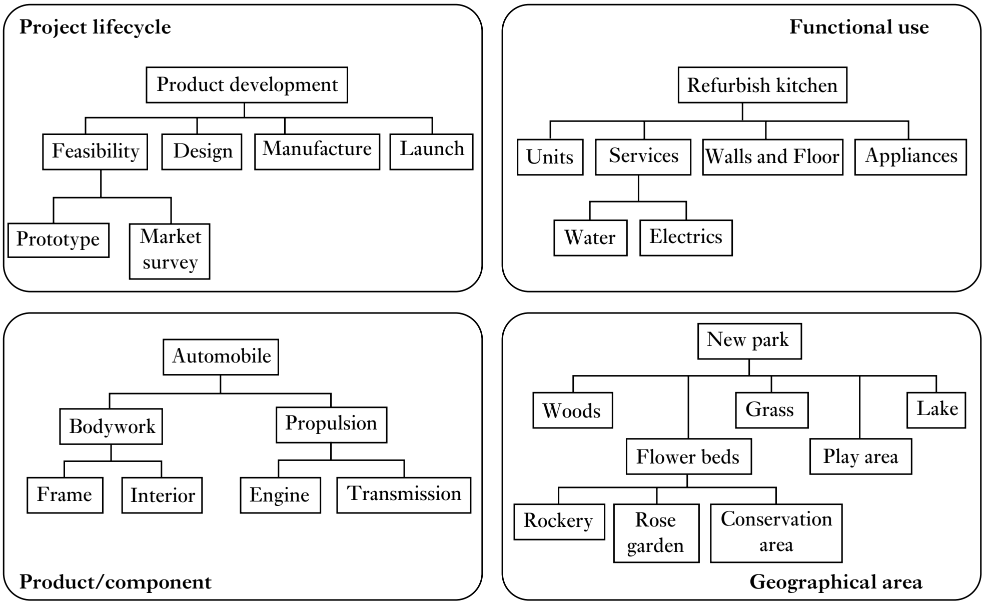


**Figure 1** Examples of work breakdown structures

## Work Packages

Work packages represent units of work at levels where the work is performed and are assignable to a single responsible organizational element. Their definition, therefore, is very important. Each work package is unique and will have its own start and end points that represent physical accomplishment. It will also have a budget, together with the resources required, and associated products or deliverables that will include "management products" such as reports and specifications. Frequently, work packages are used to represent a high level program that details how the project will be carried out, i.e., the execution plan of the project (*see* NETWORK TECHNIQUES).

Once the work packages have been defined, they provide the benefits of baseline definition for subsequent change control, risk identification and assessment, assignment of responsibility, and identification of resources. The approach insures completeness by the discipline of a standard approach. Future projects also benefit, as work packages can form building blocks as an aid to estimating future projects.

## A Framework for Control

The WBS can be the heart of an integrated project management information system by relating the work to be performed, the organization structure, and the individual responsibilities for the work. It forms the foundation for planning and budgeting and subsequent detailed activity or task planning. A valuable side benefit is to formulate packages of work for subcontracting to other organizations to reduce the risk to the project due to lack of expertise or resources (*see* PROJECT RISK MANAGEMENT). Most modern project management information systems provide analysis, reporting, and control based on WBS structures to enable decisions to be made with the overview information given by a WBS.

See also *project cost management and control; project management*

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### work measurement

*John Heap*

Work measurement is the process of establishing the time that a given task would take when performed by a qualified worker working at a defined level of performance. There are various ways in which work may be measured and a variety of techniques have been established. The basic procedure, irrespective of the particular measurement technique being used, consists of three stages:

1. an analysis phase in which the job is divided into convenient, discrete components, commonly known as elements;
2. a measurement phase in which the specific measurement technique is used to establish the time required (by a qualified worker working at a defined level of performance) to complete each element of work;
3. a synthesis phase in which the various elemental times are added, together with appropriate allowances (see below), to construct the standard time for the complete job.

The techniques used to measure work can be classified into those that rely on direct observation of the work, and those that do not. For example, some techniques, such as PREDETERMINED MOTION TIME SYSTEMS and the use of synthetic or standard data, can provide times from simulation or even visualization of the work. However, the data on which such techniques are based were almost certainly based on earlier observation of actual work.

Direct observation techniques (such as TIME STUDY and ANALYTICAL ESTIMATING) include a process for converting observed times to times for the "qualified worker working at a defined level of performance." The commonest of these processes is known as rating. This involves the observer (after appropriate training) making an assessment of the worker's rate of working relative to the observer's concept of the rate corresponding to standard rating. This assessment is based on the factors involved in the work – such as effort, dexterity, speed of movement, and consistency. The assessment is made on a rating scale, of which there are three or four in common usage. Thus on the 0–100 scale, the observer makes a judgment of the worker's rate of working as a percentage of the standard rate of working (100). The rating is then used (in a process known as "extension" in time study) to convert the observed time to the basic time using the simple formula:

$$\text{Basic time} = \frac{\text{observed time} \times \text{observed rating}}{\text{standard rating}}$$

Rating is regarded by many as a controversial area of measurement since it is a subjective assessment. Where different observers rate differently, the resulting basic times are not comparable. It is seen as important by work measurement practitioners to insure that those undertaking the rating are properly trained and that this training is regularly updated (to maintain a common perception of standard rating) through rating clinics.

When carrying out work over a complete shift or working day, workers obviously suffer from the fatigue imposed both by the work undertaken and by the conditions under which they are working. The normal practice is to make an addition to the basic time (commonly referred to as an "allowance") to allow the worker to recover from this fatigue and to attend to personal needs. The amount of the allowance depends on the nature of the work and the working environment and is often assessed using an agreed set of guidelines and scales. It is usual to allow some of the recovery period inherent in these allowances to be taken away from the workplace (and it is essential in adverse working conditions). Thus, work design should include the design of an effective work–rest regime. The addition of allowances should never be used to compensate for an unsafe or unhealthy working environment.

One minority school of thought suggests that relaxation allowances are unnecessary. When work involves, say, the carrying of heavy weights, this school suggests that the observer automatically adjusts the concept of standard rating to allow for the weight. Thus, if the standard rate of performance for walking on level ground carrying no weight is equivalent to 4 miles per hour, then an observer rating a worker walking while carrying a weight will not expect the equivalent rate. Thus, it is argued, the weight has been allowed for in the adjustment of standard rating and any relaxation allowance is simply a duplication of this adjustment.

In many jobs there are small amounts of work that may occur irregularly and inconsistently. It is often not economic to measure such infrequent work and an additional allowance is added to cover such work and similar irregular delays. This allowance is known as a contingency allowance and is assessed by observation, by analysis of historical records (for such items as tool sharpening or replacement), or by experience.

The end result is a standard time that includes the time the work "should" take (when carried out by a qualified worker), plus additional allocations in the form of allowances, where appropriate, to cover relaxation time, contingency time, and, perhaps, unoccupied time that increases the overall work cycle (such as waiting for a machine to finish a processing cycle).

The choice of a suitable measurement technique depends on a number of factors, including the purpose of the measurement, the level of detail required, the time available for the measurement, the existence of available predetermined data, and the cost of measurement.

To some extent there is a trade off between some of these factors (*see* TRADE OFFS). For example, techniques that derive times quickly may provide less detail and be less suitable for some purposes, such as the establishment of individual performance levels on short cycle work.

The advantage of structured and systematic work measurement is that it gives a common currency for the evaluation and comparison of all types of work. The results obtained from work measurement are commonly used as the basis of the planning and scheduling of work, manpower planning, work balancing in team working, costing, labor performance measurement, and financial incentives. They are less commonly used as the basis of product design, methods comparison, work sequencing, and workplace design.

See also *work study; work time distributions*

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## work organization

*David Bennett*

Work organization is a general term that is used to describe the way in which the people in the production or operation system can be organized and directed toward meeting its output objectives. In some respects work organization is closely related to JOB DESIGN and the two terms are sometimes used interchangeably. However, work organization is a wider concept that can embrace the organization of the entire production function of an enterprise, whereas job design focuses on the structure of individual jobs at the workplace, or groups of jobs around a discrete production system such as a line or cell.

A particular feature influencing work organization has been the increasing effect of mechanization and automation of operations, which in turn has led to greater differentiation and predetermination of work. Set against this trend has been the demand for greater self actualization and the need to create "higher levels" of work to satisfy an increasingly better educated work force. Because of this, the organization of work is no longer a straightforward matter of applying the simple principles of SCIENTIFIC MANAGEMENT that were developed in the early part of the twentieth century. Rather, it needs to take account of human behavior, group dynamics, and the sociotechnical systems concepts that recognize the interaction between workers and technology.

Although work organization is a complex subject, it is helpful to understand that in practice there are only a limited number of basic ways the human resources in a production or operation system can actually be oriented. These are by product, by process, or by task.

Product oriented work organization is based on the idea of a worker, or group of workers, completing an identifiable "product" (which could be a discrete part of the final product, the final product itself, or a service). The required tasks are grouped (though not necessarily carried out together, nor in a particular order), and there is usually some discretion as to how they are carried out.

Process oriented work organization exploits the principle of DIVISION OF LABOR by enab ling similar operations to be performed repeat edly on a whole range of components and products (or service elements). Here the prod ucts, rather than the tasks, are grouped and there is less discretion as to how the work is carried out.

Task oriented work organization takes the idea of division of labor and specialization to its logical conclusion by adopting the approach of repeated performance of short cycle time tasks on part completed components and products (or services) which, by virtue of their demand, are produced continuously. Here there is neither grouping of tasks nor of products, and there is virtually no discretion as to how the work is to be carried out.

Much of the recent research on work organ ization has tended to focus on the problems associated with task and process orientation. These problems largely result from the alien ation of people who are employed in these re petitive types of work. As a result, many of the alternative forms, such as GROUP WORKING based on a CELL LAYOUT, have a product orientation that can allow a greater degree of association with the product and the wider enterprise.

See also *empowerment; job enlargement; job enrichment; job rotation; method study; telework ing*

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## work study

*Nigel Slack*

Work study is a general term for the study of human work, based originally on the principles of SCIENTIFIC MANAGEMENT. It includes a number of techniques that are generally divided into those that contribute to METHOD STUDY and those that contribute to WORK MEASURE MENT. These two topics are generally seen as the two subcategories of work study activity. The aim of work study is a systematic investi gation of work that will lead to improvements, especially in the efficiency with which the work is carried out.

See also *analytical estimating; division of labor; predetermined motion time systems; time study; work time distributions*

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## work-time distributions

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A characteristic of human work is that, when engaged on repetitive work, any person will not always take the same amount of time in perform ing a task. Most studies hold that when working under motivated and unpaced conditions (i.e., where machines are not directly limiting or ac celerating individual work times), a qualified person will work such that the distribution of task times is positively skewed. Exceptions to this general rule are where the person performing the task is either not experienced or not trained in the task, in which case the distribution of work times is more likely to be symmetrical, or where some element of artificial pacing is present in the task, which again has the effect of producing a symmetrical work time distribution.

Although there is unanimity in describing the shape of unpaced work time distributions as being positively skewed with a lower limit below which the task cannot be completed, there is less agreement over the extent of variability and skewness to be expected. Partly this is explained by the fact that no one value of either variability or skewness will uniquely represent all unpaced work time distributions since the nature of the task itself will largely determine such values. However, an understanding of typical values is important in so far as it directly affects the performance of production systems connected in series. Most studies seem to indicate a surprisingly close range of results for the variance of work time distributions, usually quoting a figure between 0.25 and 0.3 for the coefficient of variation of such distributions. There is less consensus over the degree of skewness to be found. However, skewness levels (measured by Pearson's first coefficient of skewness) of around 0.5 have been found to be typical.

See also *predetermined motion time systems; time study; work measurement; work study*

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# Z

**zone of tolerance**

*Robert Johnston*

The zone of tolerance is usually defined as the range of customer perceptions of a service between desired and minimum acceptable standards (Zeithaml, Berry, and Parasuraman, 1993). In essence it is the range of service performance that a customer considers satisfactory. Performance below the zone is seen as dissatisfying and performance above the zone is seen as delighting.

The importance of this zone of tolerance is that customers may accept variation within a range of performance, and any increase or decrease in performance within this area will only have a marginal effect on perceptions. Only when performance moves outside this range will it have any real effect on perceived service quality. If a customer's zone of tolerance is narrow, then he or she may be highly sensitive to the service experience, with a greater likelihood of dissatisfying or delighting outcomes. Conversely, if a customer has a wide zone of tolerance, then he or she may be much less sensitive to the service experience, thus increasing the likelihood of a satisfactory or acceptable outcome.

The width of the zone of tolerance may vary from customer to customer and from situation to situation. There are three things that might affect the width of a customer's zone of tolerance: (1) the customer's involvement with the service; (2) the importance of individual quality factors (*see* QUALITY CHARACTERISTICS); and (3) the outcomes of encounters during the service process itself.

1 The width of the zone of tolerance is affected by the customer's degree of involvement in the service. Involvement concerns a customer's perceived importance of the service. This may be influenced by, for example, the customer's emotional involvement with the service, past experiences, and knowledge of alternative service offerings. The greater the involvement, the more sensitive is the customer to the service and the narrower is the width of his or her zone of tolerance.
2 The width of the zone may vary for each individual quality factor. The more important a characteristic, the narrower is the zone of tolerance. Reliability, for example, tends to be the most important and therefore the one where customers' perceptions are the most sensitive to service performance.
3 The width of the zone of tolerance may be affected during the service itself by particularly dissatisfying or delighting service encounters or transactions (Johnston, 1995). A failure in a single transaction or encounter may sensitize customers to negative aspects of the service. Customers may become more aware of, and indeed actively seek out, other negative experiences. A dissatisfying transaction will therefore have the effect of raising the lower threshold, making a dissatisfying outcome more likely. Conversely, a delighting transaction during the service process may sensitize the customer to notice other successes, thus lowering their upper threshold and making a highly satisfactory outcome more likely. Transactions that might previously have been seen as satisfying may now be seen as delighting as the customer has become more positively disposed toward the service.

See also *order winners and qualifiers; service quality*

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# Index

Note: Headwords are in bold type