Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering
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Teaching Course Material

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1. Introduction

The fundamentals of production and operations management (P/OM) have been undergoing substantial changes over the past many decades. P/OM books must reflect these changes.

On successful completion of this module students would be able to:

- ✓ Demonstrate an understanding of production as a process of converting or transforming resources into products;
- ✓ Demonstrate an understanding of the manager's concern in planning, organizing, directing, and controlling productive operations to meet organizational objectives;
- ✓ Demonstrate an understanding of productivity measures, quality and costs both, direct and indirect; and
- ✓ Use a variety of problem-solving techniques to aid in effective decision making.

Chapter One

1. Introduction: Operations Planning Concepts

This part defines production and operations management (P/OM) and explains how this management field is applicable to both manufacturing and services, as well as to both profit-making and not-for-profit organizations. This part also elaborates the advantages of using the systems perspective, which links P/OM to all other managerial functions in the organization.

1.1. **Operations Functions in Organizations**,

Operations is that part of a business organization that is responsible for producing goods and/or services. Goods are physical items that include raw materials, parts, subassemblies such as motherboards that go into computers, and final products such as cell phones and automobiles. Services are activities that provide some combination of time, location, form, or psychological value. Examples of goods and services are found all around you. Every book you read, every video you watch, every e-mail or text message you send, every telephone conversation you have, and every medical treatment you receive involves the operations function of one or more organizations. So does everything you wear, eat, travel in, sit on, and access the Internet with. The operations function in business can also be viewed from a more far-reaching perspective: The collective success or failure of companies' operations functions has an impact on the ability of a nation to compete with other nations, and on the nation's economy.

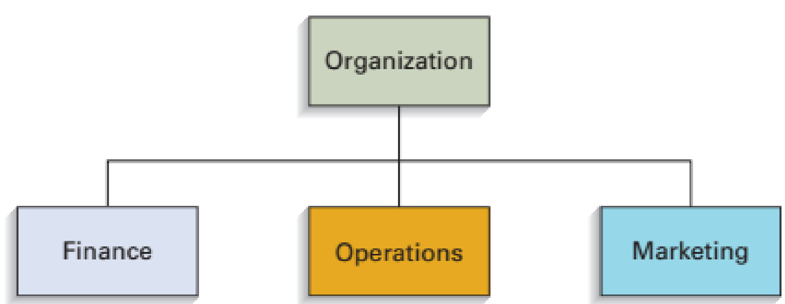

Figure 1.1: The three basic functions of business organizations

1.2. Historical Development of Operation Management

Systems for production have existed since ancient times. For example, the construction of pyramids and Roman aqueducts involved operations management skills. The production of goods for sale, at least in the modern sense, and the modern factory system had their roots in the Industrial Revolution.

The Industrial Revolution

The Industrial Revolution began in the 1770s in England and spread to the rest of Europe and to the United States during the 19^{th} century. Prior to that time, goods were produced in small shops by craftsmen and their apprentices. Under that system, it was common for one person to be responsible for making a product, such as a horse-drawn wagon or a piece of furniture, from start to finish. Only simple tools were available; the machines in use today had not been invented.

Then, a number of innovations in the 18th century changed the face of production forever by substituting machine power for human power. Perhaps the most significant of these was the steam engine, because it provided a source of power to operate machines in factories.

Ample supplies of coal and iron ore provided materials for generating power and making machinery. The new machines, made of iron, were much stronger and more durable than the simple wooden machines they replaced.

In the earliest days of manufacturing, goods were produced using craft production: highly skilled workers using simple, flexible tools produced goods according to customer specifications. Craft production had major shortcomings. Because products were made by skilled craftsmen who custom-fitted parts, production was slow and costly. And when parts failed, the replacements also had to be custom made, which was also slow and costly. Another shortcoming was that production costs did not decrease as volume increased; there were no economies of scale, which would have provided a major incentive for companies to expand. Instead, many small companies emerged, each with its own set of standards.

A major change occurred that gave the Industrial Revolution a boost: the development of standard gauging systems. This greatly reduced the need for custom-made goods. Factories began to spring up and grow rapidly, providing jobs for countless people who were attracted in large numbers from rural areas.

Despite the major changes that were taking place, management theory and practice had not progressed much from early days. What was needed was an enlightened and more systematic approach to management.

Scientific Management

The scientific management era brought widespread changes to the management of factories. The movement was spearheaded by the efficiency engineer and inventor Frederick Winslow Taylor, who is often referred to as the father of scientific management. Taylor believed in a "science of management" based on observation, measurement, analysis and improvement of work methods, and economic incentives. He studied work methods in great detail to identify the best method for doing each job. Taylor also believed that management should be responsible for planning, carefully selecting and training workers, finding the best way to perform each job, achieving cooperation between management and workers, and separating management activities from work activities.

Taylor's methods emphasized maximizing output. They were not always popular with workers, who sometimes thought the methods were used to unfairly increase output without a corresponding increase in compensation. Certainly some companies did abuse workers in their quest for efficiency. Eventually, the public outcry reached the halls of Congress, and hearings were held on the matter. Taylor himself was called to testify in 1911, the same year in which his classic book, The Principles of Scientific Management, was published. The publicity from those hearings actually helped scientific management principles to achieve wide acceptance in industry.

A number of other pioneers also contributed heavily to this movement, including the following:

- ✓ Frank Gilbreth was an industrial engineer who is often referred to as the father of motion study. He developed principles of motion economy that could be applied to incredibly small portions of a task.
- ✓ Henry Gantt recognized the value of nonmonetary rewards to motivate workers, and developed a widely used system for scheduling, called Gantt charts.
- ✓ Harrington Emerson applied Taylor's ideas to organization structure and encouraged the use of experts to improve organizational efficiency. He testified in a congressional hearing that railroads could save a million dollars a day by applying principles of scientific management.
- ✓ Henry Ford, the great industrialist, employed scientific management techniques in his factories.

During the early part of the 20th century, automobiles were just coming into vogue in the United States. Ford's Model T was such a success that the company had trouble keeping up with orders for the cars. In an effort to improve the efficiency of operations, Ford adopted the scientific management principles espoused by Frederick Winslow Taylor. He also introduced the moving assembly line, which had a tremendous impact on production methods in many industries.

Among Ford's many contributions was the introduction of mass production to the automotive industry, a system of production in which large volumes of standardized goods are produced by low-skilled or semiskilled workers using highly specialized, and often costly, equipment. Ford was able to do this by taking advantage of a number of important concepts.

Perhaps the key concept that launched mass production was interchangeable parts, sometimes attributed to Eli Whitney, an American inventor who applied the concept to assembling muskets in the late 1700s. The basis for interchangeable parts was to standardize parts so that any part in a batch of parts would fit any automobile coming down the assembly line.

This meant that parts did not have to be custom fitted, as they were in craft production. The standardized parts could also be used for replacement parts. The result was a tremendous decrease in assembly time and cost. Ford accomplished this by standardizing the gauges used to measure parts during production and by using newly developed processes to produce uniform parts.

A second concept used by Ford was the division of labor, which Adam Smith wrote about in The Wealth of Nations (1776). Division of labor means that an operation, such as assembling an automobile, is divided up into a series of many small tasks, and individual workers are assigned to one of those tasks. Unlike craft production, where each worker was responsible for doing many tasks, and thus required skill, with division of labor the tasks were so narrow that virtually no skill was required.

Together, these concepts enabled Ford to tremendously increase the production rate at his factories using readily available inexpensive labor. Both Taylor and Ford were despised by many workers, because they held workers in such low regard, expecting them to perform like robots. This paved the way for the human relations movement.

The Human Relations Movement

Whereas the scientific management movement heavily emphasized the technical aspects of work design, the human relations movement emphasized the importance of the human element in job design. Lillian Gilbreth, a psychologist and the wife of Frank Gilbreth, worked with her husband, focusing on the human factor in work. (The Gilbreths were the subject of a classic film, Cheaper by the Dozen.) Many of her studies dealt with worker fatigue. In the following decades, there was much emphasis on motivation. Elton Mayo conducted studies at the Hawthorne division of Western Electric. His studies revealed that in addition to the physical and technical aspects of work, worker motivation is critical for improving productivity. Abraham Maslow developed motivational theories, which Frederick Hertzberg refined.

Douglas McGregor added Theory X and Theory Y. These theories represented the two ends of the spectrum of how employees view work.

- ✓ Theory X, on the negative end, assumed that workers do not like to work, and have to be controlled—rewarded and punished—to get them to do good work. This attitude was quite common in the automobile industry and in some other industries, until the threat of global competition forced them to rethink that approach.
- ✓ Theory Y, on the other end of the spectrum, assumed that workers enjoy the physical and mental aspects of work and become committed to work. The Theory X approach resulted in an adversarial environment, whereas the Theory Y approach resulted in empowered workers and a more cooperative spirit.
- ✓ William Ouchi added Theory Z, which combined the Japanese approach with such features as lifetime employment, employee problem solving, and consensus building, and the traditional Western approach that features short-term employment, specialists, and individual decision making and responsibility.

Decision Models and Management Science

The factory movement was accompanied by the development of several quantitative techniques. F. W. Harris developed one of the first models in 1915: a mathematical model for inventory order size. In the 1930s, three coworkers at Bell Telephone Labs, H. F. Dodge, H. G. Romig, and W. Shewhart, developed statistical procedures for sampling and quality control. In 1935, L.H.C. Tippett conducted studies that provided the groundwork for statistical sampling theory.

At first, these quantitative models were not widely used in industry. However, the onset of World War II changed that. The war generated tremendous pressures on manufacturing output, and specialists from many disciplines combined efforts to achieve advancements in the military and in manufacturing. After the war, efforts to develop and refine quantitative tools for decision making continued, resulting in decision models for forecasting, inventory management, project management, and other areas of operations management.

During the 1960s and 1970s, management science techniques were highly regarded; in the 1980s, they lost some favor. However, the widespread use of personal computers and user-friendly software in the workplace contributed to a resurgence in the popularity of these techniques.

Table 1.1: Historical Development of Operations Management

Concept	Time	Explanation
Industrial Revolution	Late 1700s	Brought in innovations that changed production by using machine power instead of human power.
Scientific management	Early 1900s	Brought the concepts of analysis and measurement of the technical aspects of work design and development of moving assembly lines and mass production.
Human relations movement	1930s to 1960s	Focused on understanding human elements of job design, such as worker motivation and job satisfaction.
Management science	1940s to 1960s	Focused on the development of quantitative techniques to solve operations problems.
Computer age	1960s	Enabled processing of large amounts of data and allowed widespread use of quantitative procedures.
Environmental issues	1970s	Considered waste reduction, the need for recycling, and product reuse.
Just-in-time systems (JIT)	1980s	Designed to achieve high-volume production with minimal inventories.
Total quality management (TQM)	1980s	Sought to eliminate causes of production defects.
Reengineering	1980s	Required redesigning a company's processes in order to provide greater efficiency and cost reduction.
Global competition	1980s	Designed operations to compete in the global market.
Flexibility	1990s	Offered customization on a mass scale.
Time-based competition	1990s	Based on time, such as speed of delivery.
Supply chain management	1990s	Focused on reducing the overall cost of the system that manages the flow of materials and information from suppliers to final customers.
Electronic commerce	2000s	Uses the Internet and World Wide Web for conducting business activity.
Outsourcing and flattening of the world	2000s	Convergence of technology has enabled outsourcing of virtually any job imaginable from anywhere around the globe, therefore "flattening" the world.

1.3. Framework for managing operations, the trend, Information and Non-manufacturing systems

The product line of goods and services determines the operations needed to match supply and demand. The business model combines marketing forces (including competition), financial investments, and operating costs. This business model had to be thought out in detail during strategic planning.

A product that cannot be made or delivered on time, with quality, and at an acceptable cost must be referred back to marketing and general management. If financial support is insufficient to develop a satisfactory process, that fact must be referred back to finance and marketing. If employee resources are inadequate to operate the processes, that fact must be referred back to HRM, marketing, finance, and general management. These and other issues place P/OM at the hub (core and center) of the business model.

The planning details (of the model), once accepted, have to be adhered to by all of the business functions. When results do not jibe with plans, it is essential that all parties reexamine original assumptions and make adjustments as soon as practicable. As will be recognized from the following discussion, the functional field approach cannot be accepted. Although this is true in general, it is particularly so in a global business environment. The systems approach is essential.

The OM language describes methods, tools, procedures, goals, and concepts that relate to the management of people, materials, facilities, energy, information, and technology. The growing recognition of the importance of the service function in manufacturing has broadened the situations to which the term operations is applied.

Manufacturers have become more comfortable with the notion that they must cater to the customer's service requirements. Information systems provide the necessary data about customer needs so that operations management can supply the required services.

Both services and manufacturing are increasingly responsive to—and controlled by—information systems. Therefore, knowledge of computers, computer programming, networking, and telecommunications is essential in both the manufacturing and service environment. The field of analytics, which combines computer power with huge amounts of data, has been growing exponentially as the comfort level of managers with computers analyzing big data has improved. Massive amounts of information can be stored and analyzed for the first time in the history of management. P/OM is at the forefront of this systems-oriented evolutionary capability.

Schools of business include both goods and services under the term operations, whereas industrial engineering departments are still inclined to teach “production” courses. Nevertheless, there is inevitable convergence of both to an information dominated workplace.

Operations is the familiar management term for an information systems environment, so the word “operations” fits nicely. Programming and maintenance (both service functions) have become increasingly important to manufacturing. Further, the relevance of service to customers increasingly is viewed as a part of the total package that the manufacturer must deliver. Manufacturing joins such distinguished service industries as transportation, banking, entertainment, education, and healthcare. In this regard, note the following **trends for manufacturing**:

- ✓ The labor component (the input of blue-collar workers) has been decreasing as a percent of the cost of goods at an accelerating rate for over 50 years. In part this explains the persistence of unemployment in the developed economies of the world.

- ✓ The technological (and capital assets) component as a percent of the cost of goods has been increasing for many years. In the past 20 years, this effect has become multiplicative, with computers controlling sophisticated and costly equipment across vast distances via satellites and networks.
- ✓ As information systems play a larger part in manufacturing, highly trained computer programmers (sometimes called gold-collar workers) and white collar supervisors add to growing sales and administrative (overhead) costs, which have to be partitioned into the cost of goods. These costs are an increasing percent of the cost of goods. Traditional methods for assigning these costs can lead to detrimental P/OM decisions. New accounting methods, called activity-based costing (ABC), should be used to improve overhead accounting. A good introduction to ABC can be found in Kaplan and Cooper (1988) and Kaplan and Anderson (2007). Operations managers need to discuss these issues with their colleagues from accounting.
- ✓ The systems approach requires communication between functions and the sharing of what used to be (and still are, in many traditional firms) mutually exclusive databases. The databases of marketing and sales, P/OM, R&D, engineering, and finance are cross-linked when advantageous. This sharing is crucial to enabling the systems approach to work. There are many examples of both manufacturing and service industries where shared databases have been installed and utilized successfully.
- ✓ The technology of the twentieth century is moving rapidly into retirement along with a lot of executives who grew up with its characteristics. The 21st century is a different ball game with new

players who feel free to deal with the distinction between services and manufacturing as well as between operations and production in their own way.

Practitioners now have stepped into the twenty-first century, but they have yet to get accustomed to it. It is a good bet that the taxonomy of the twenty-first century will categorize production as a subheading under operations, and services will be an integral part of manufacturing. Inter-functional planning with shared information will be the norm and not the exception.

When a discussion applies equally well to both manufacturing and services, it is often referred to as P/OM. As explained earlier, it is increasingly common to call it OM. However, in this book, we will use the terms P/OM and OM interchangeably. Because we are straddling the 20th and 21st centuries, we tend to use P/OM most often. We do so to be as inclusive as possible.

1.4. Operations management

Operations are purposeful actions (or activities) methodically done as part of a plan of work by a process that is designed to achieve practical ends and concrete objectives. This definition is applicable to both manufacturing and services organizations. This interpretation further justifies the use of the term operations for manufacturing. An operations manager is responsible for planning, organizing, coordinating, and controlling organizational resources to produce desired goods and services.

The generic or collective definition of operations emphasizes rational design, careful control, and the systematic approach that characterizes the methodology of P/OM. Production/operations is a big umbrella that always includes services and often includes manufacturing.

P/OM is the systematic planning, execution, and control of operations. This definition implies that management is needed to ensure that actions are purposeful—designed to achieve practical goals and targets. P/OM makes sure that the work is done methodically, that is, characterized by method and order. The fact that a process is used suggests the presence of management to install a procedure for working systematically.

Operations management is responsible for a plan of work—a thoughtful progression from one step to another. Plans require details for accomplishing work. These details are often called the tactics of the plan. Practical ends are not realized without operations management that is able to provide strategies and tactics for public service objectives, which can include the ability to gain market share on a bus route or participation in a recycling plan. Everyone wants to be able to gain market share. Strangely, the same does not apply to profit. Non-profit organizations pay salaries and provide services which are profits transformed—always labeled as expenditures. There is a need to review why some organizations consider it embarrassing to make a profit.

Operations management uses methodology that consists of procedures, rules of thumb, and algorithms for analyzing situations and setting policies. They apply to many different kinds of service and manufacturing processes. In brief, operations management consists of tactics such as scheduling work, assigning resources including people and equipment, managing inventories, assuring quality standards, process-type decisions that include capacity decisions, maintenance policies, equipment selection, worker-training options, and the sequence for making individual items in a product-mix set.

Manufacturing Operations

Manufacturing operations transform materials into desired goods and products. Operations can be described using different verbs and object phrases such as pressing and turning metal (on a lathe), cutting paper, sewing clothes, sawing and drilling wood, sandblasting glass, forming plastics, shaping clay, heat-treating materials, soldering contacts, weaving fabric, blending fuels, filling cans, and extruding wires. Similarly, there are a variety of assembly phrases, such as snapping together parts, gluing sheets, fitting components, joining pieces together, preparing (assembling) a burger. Products such as automobiles, airplanes, televisions, furniture suites, computers, refrigerators, and light bulbs are made in factories. On the other hand, fast-food chains such as McDonald's and Burger King view the assembly of sandwiches from meat, buns, and condiments as a manufacturing application. Goods also include processed items such as paint, milk, cheese, chemicals, etc. While there is a notable distinction between fresh foods and factory foods, much of agriculture is a production process.

Service Operations

Service operations in the office environment are quite familiar, that is, filing documents, typing input for the word processor, and answering the phone. There are similar lists of verbs and objects that apply to jobs done in banks, hospitals, and schools: granting loans, taking X-rays, and teaching classes are a few examples. Movies are one of the biggest export products of the United States. Operations management applies directly to entertainment, film-making, and sports. Administration of the law is a major service industry that requires operations management. Law firms are well aware of the importance of productivity management, information systems, and quality improvement. Jobs available for operations managers of law firms are one indication of the extent to which OM savvy lawyers are highly valued.

Those who have worked for UPS, Federal Express, or the post office are able to list the various service operations related to delivering mail and packages. Those who have worked for the IRS will have another set of job descriptions to define specific operations that characterize tax collection activities of the federal government. Also, if one has worked for The Gap, Banana Republic, Eddie Bauer, The Limited, Wal-Mart, The Sharper Image, Kmart, Sears, or other retail operators, he or she will be able to define processes that are pertinent to merchandise selection and pricing, outsourcing, distribution logistics, display, and store retailing. The experience will have similarities and differences with supermarkets that must also cope with dated products such as milk and greens that speak for themselves (besides being labeled) regarding freshness. Successful mail-order (and Internet) companies like Lands' End, Amazon, L.L. Bean, Victoria's Secret, Norm Thompson, and Barnes & Noble are good examples of entrepreneurial firms that have struggled to master changes in technologies to gain the operational advantages of smart logistics. Distribution, in retail, mail order, and Internet B2C (business-to-consumer web customers), is a production process that lends itself to all of the benefits to all of the benefits that excellent information systems and new technology can bestow.

The credit card business is another splendid example of a situation that combines many aspects of service functions. MasterCard, VISA, and American Express are totally dependent on smart operations management to provide profit margin excellence. The IT component of the credit card business model is almost transparent, but it is still very difficult to do well with consistent performance. These production processes are good examples of information systems operating under high-volume flow shop conditions.

Disaster (crisis) management, another service area, is an emerging field within the realm of P/OM. A disaster can be man-made through error and/or terror; or naturedriven such as flooding, fires, earthquakes, hurricanes, and volcanic eruptions. With an increase in the frequency of disasters—both natural and manmade—the importance of crisis management has increased. First responders to crises must cope with needs of people buried, injured, starving, thirsty, and requiring shelter. They need supplies and equipment. In this instance, crisis management anticipates needs before they arise based on understanding the type of disaster that is predicted. Dealing with the aftermaths of tragedies requires a priori analysis of supply chains to deliver healthcare and subsistence. This point of view is understandable since alleviating human suffering deserves top priority.

1.5. Factors affecting productivity and International dimensions of productivity

Productivity is a critical business variable that directly impacts the "bottom line"; improved productivity raises net profits. P/OM is responsible for the productivity of the process. This is such a critical factor in a company's overall success that excellence in productivity achievement is a major P/OM issue. Productivity measures the performance of the organization's processes for doing work. Productivity is defined as the ratio measure of output (O) divided by input (I). Operations management views the measurement of productivity as essential for assessing the performance of an organization's productive capacity over a specific time period and in comparison to the competition. When outputs are high and inputs are low, the system is said to be efficient and productive, but everything is relative or should we say competitive?

Productivity is relatively easy to measure for physical goods. It is more difficult to find appropriate measures for some services outputs such as units of education or healthcare. Creative knowledge workers provide other instances of intangible outputs that are highly valued, but elusive to calculate. The effort has to be made to appraise the value of these outputs in a standardized way to provide a benchmark (or standard) for measurement.

Operations management views the measurement of productivity as an essential tool for assessing the performance of an organization's productive capacity over a specific time period and in comparison to the competition. When outputs are high and inputs are low, the system is said to be efficient and productive. The APICS Dictionary definition of productivity can be converted into the terms of this text by recognizing that productivity is the ratio measure of the output divided by the input as given by:

$$\text{Productivity} = \frac{\text{Outputs}}{\text{Inputs}} = \text{Measure of production efficiency}$$

This productivity measure compares the quantity of goods or services produced in a period of time (t) and the quantity of resources employed in turning out these goods or services in the same period of time (t) (Fabricant 1969). Creative knowledge workers provide other instances of intangible outputs that are highly valued, but elusive to calculate. The effort has to be made to appraise the value of these outputs in a standardized way to provide a benchmark (or standard) for measurement. Several authors have proposed ways to measure service productivity. Some of these are described below. Levitt (1972), in his article, Production Line Approach to Service, argues that, "if customer service is consciously treated as 'manufacturing in the field,' it will get the same kind of detailed attention that manufacturing gets. It will be carefully planned, controlled, automated where possible, audited for quality control, and regularly reviewed for performance improvement and customer reaction." In the article, managing Our Way to Higher Service-Sector Productivity, Biema and Greenwald (1997) also argue that productivity improvement techniques used in manufacturing sector are applicable to service sector as well in spite of the complexity of the service sector.

According to Drucker (1999), improving knowledge–worker productivity is one of the biggest challenges in the twenty-first century. He lists six major determinants of knowledge–worker productivity. These include: offer a clear task definition, put responsibility for productivity on workers themselves and provide autonomy, use continuous innovation, continuous learning and teaching, focus on quality and not only quantity of output, and treat knowledge worker as an "asset" rather than a "cost." Improving the productivity of specific service businesses has been the focus of attention of several other authors also—for example, hospitals and banks by Sherman (1984), Bell Labs by Kelley and Caplan (1993), and sales force by Ledingham et al. (2006).

Productivity measures are benchmarks for comparing how well the system is doing compared to other systems, or over time. The comparisons include: how A is doing over time; how A compares to B; how departments within A compare to each other; how A compares to an industry average; how A compares to the best of the industry, etc. Sales perceives productivity as high customer sales volume (called an effective marketing system) accompanied by low producer costs (called an efficient producer system). Thus:

$$\text{Productivity} = \frac{\text{Effectiveness}}{\text{Efficiency}} = \frac{\text{High customer sales volume}}{\text{Low producer expenses}}$$

From a systems point of view, the inclusion of sales provides a correct measure of output for productivity measurement. It is never productive to make a lot of product that is not sold, even if the cost of making it is low. At the same time, P/OM employs productivity measures to assess how well the production system is functioning. The kinds of questions that are being addressed are: how many units of resources are consumed to produce the output, and how many units of output can be made with a fixed amount of capacity? These are blueprints for productivity improvement. Both ways of viewing productivity have benefits. They stem from different interests that need to be shared. The best interests of the company are served by merging what is learned about P/OM's efficiency and sales/marketing effectiveness.

Labor Productivity

Labor efficiency is an often-used measure of productivity where productivity is a ratio of output units produced to input labor resources expended per unit of time (t). The following equation gives the dimensions for output and input

Output = units per hour and Input dollars per hour = hourly wages

Measures labor productivity over a specific period of time, t, and gives the relationship between the dollars of labor resources required in period (t) to achieve the output rate (t). This is a measure of how much output is being obtained for each dollar spent:

$$\text{Productivity}(t) = \frac{\text{Output}(t)}{\text{Input}(t)} = \frac{\text{Units of output}(t)}{\text{Dollars of labor}(t)}$$

Another way of stating the measure of productivity is to put a dollar value on the output volume per unit of time (t) as given in the following equation:

$$\text{Labor productivity}(t) = \frac{\text{Output}(t)}{\text{Input}(t)} = \frac{\text{Sales in dollars}(t)}{\text{Dollars of labor}(t)}$$

The advantage of this method is that it can deal with the productivity of the system across different kinds of units. For example, the productivity of a paint company that puts paints of many colors in cans of many sizes could be measured. This approach is used for national accounting of productivity where there are many different kinds of units to be included (i.e., furniture, clothing, energy, and food). Dollars can standardize the output measure across diverse categories. Labor productivity, often measured as the ratio of sales dollars to labor cost dollars, is called a partial measure of productivity. It is partial because it only looks at labor and does not include capital.

Capital Productivity

There are also other factors that can be used to measure productivity. For example, capital may be used as an input resource in place of labor, or both capital and labor may be used. Capital productivity is the productivity of the invested capital in technology. The following Equation measures capital productivity as the number of units of output per dollar of invested capital:

$$\text{Capital productivity}(t) = \frac{\text{Output}(t)}{\text{Input}(t)} = \frac{\text{Units of output}(t)}{\text{Dollars of capital}(t)}$$

Whereas the following Equation measures capital productivity as a pure ratio based on dollars of output per dollar of invested capital:

$$\text{Capital productivity}(t) = \frac{\text{Dollar value of output units}(t)}{\text{Dollars of capital resources}(t)}$$

Such measures of capital productivity might help organizations in the service sectors to address the value of returns on investments in computers and telecommunications. By extending this reasoning, it is possible to develop other partial measures of productivity with respect to areas such as energy expended, space utilized, and materials consumed.

Partial productivity

Productivity computed as a ratio of output to only one input (e.g., labor, materials, and machines). Often it is much more useful to measure the productivity of one input variable at a time in order to identify how efficiently each is being used. When we compute productivity as the ratio of output relative to a single input, we obtain a measure of partial productivity, also called single-factor productivity.

Multifactor Productivity

Multifactor productivity (MFP) can be measured in different ways. As shown in Equation 2.8, sales and finished goods are considered as outputs, but work-in-process is not. Also, labor costs and capital expenditures (amortized) are treated as inputs. MFP (see Equation 2.8) is measured as the ratio of dollars earned to dollars spent. Total factor productivity is another name associated with inclusion of more factors than labor. Multifactor (and total factor) productivity is measured on a regular basis to determine how well the US industrial base is doing and whether it is improving its competitive position in the world.

$$\text{Multifactor productivity}(t) = \frac{\text{All outputs of goods and services}(t;\$)}{\text{Total input resources expended}(t,\$)}$$

A change in multifactor productivity reflects the difference between the change in output (production of goods and services) and the change in labor and capital inputs engaged in the production of the output. Multifactor productivity does not measure the specific contributions of labor, capital, or any other factor of production. Instead, it reflects the joint effects of many factors, including new technology, economies of scale, managerial skill, and change in the organization of production.

Total Productivity Measure	$\frac{\text{Output produced}}{\text{All inputs used}}$
Partial Productivity Measure	$\frac{\text{Output}}{\text{Labor}}$ *or* $\frac{\text{Output}}{\text{Machines}}$ *or* $\frac{\text{Output}}{\text{Materials}}$ *or* $\frac{\text{Output}}{\text{Capital}}$
Multifactor Productivity Measure	$\frac{\text{Output}}{\text{Labor + machines}}$ *or* $\frac{\text{Output}}{\text{Labor + materials}}$ *or* $\frac{\text{Output}}{\text{Labor + capital + energy}}$

Productivity measures

Example of productivity: Long Beach Bank employs three loan officers, each working eight hours per day. Each officer processes an average of five loans per day. The bank's payroll cost for the officers is $820 per day, and there is a daily overhead expense of $500. The bank has just purchased new computer software that should enable each officer to process eight loans per day, although the overhead expense will increase to $550. Evaluate the change in labor and multifactor productivity before and after implementation of the new computer software.

- **Solution:**

$$\text{Labor productivity (old)} = \frac{3 \text{ officers} \times 5 \text{ loans/day}}{24 \text{ labor-hours}} = \frac{15 \text{ loans/day}}{24 \text{ labor-hours}}$$

$$= 0.625 \text{ loans per labor-hour}$$

$$\text{Labor productivity (new)} = \frac{3 \text{ officers} \times 8 \text{ loans/day}}{24 \text{ labor-hours}} = \frac{24 \text{ loans/day}}{24 \text{ labor-hours}}$$

$$= 1.00 \text{ loan per labor-hour}$$

$$\text{Multifactor productivity (old)} = \frac{15 \text{ loans/day}}{\$820/\text{day} + \$500/\text{day}} = 0.0113 \text{ loans/dollar}$$

$$\text{Multifactor productivity (new)} = \frac{24 \text{ loans/day}}{\$820/\text{day} + \$550/\text{day}} = 0.0175 \text{ loans/dollar}$$

The change in labor productivity is from 0.625 to 1.00 loans per labor-hour. This results in an increase of 1.00/0.625= 1.6, or an increase of 60 percent. The change in multifactor productivity is from 0.0113 to 0.0175 loans per dollar. This results in an increase of 0.0175/0.0113= 1.55, or an increase of 55 percent.

Factors That Affect Productivity

Numerous factors affect productivity. Generally, they are methods, capital, quality, technology, and management. A commonly held misconception is that workers are the main determinant of productivity. According to that theory, the route to productivity gains involves getting employees to work harder. However, the fact is that many productivity gains in the past have come from technological improvements. Familiar examples include

Fax machines	Automation	GPS devices
Copiers	Calculators	Smart phones
The Internet, search engines	Computers	Apps
Voice mail, cellular phones	E-mail	3-D printing
	Software	Medical imaging

However, technology alone won't guarantee productivity gains; it must be used wisely and thoughtfully. Without careful planning, technology can actually reduce productivity, especially if it leads to inflexibility, high costs, or mismatched operations. Another current productivity pitfall results from employees' use of computers or smart phones for no work-related activities (playing games or checking stock prices or sports scores on the Internet or smart phones, and texting friends and relatives). Beyond all of these is the dip in productivity that results while employees learn to use new equipment or procedures that will eventually lead to productivity gains after the learning phase ends.

Other factors that affect productivity include the following:

Standardizing processes and procedures wherever possible to reduce variability can have a significant benefit for both productivity and quality.

Quality differences may distort productivity measurements. One way this can happen is when comparisons are made over time, such as comparing the productivity of a factory now with one 30 years ago. Quality is now much higher than it was then, but there is no simple way to incorporate quality improvements into productivity measurements.

Use of the Internet can lower costs of a wide range of transactions, thereby increasing productivity. It is likely that this effect will continue to increase productivity in the foreseeable future.

Computer viruses can have an immense negative impact on productivity.

Searching for lost or misplaced items wastes time, hence negatively affecting productivity.

Scrap rates have an adverse effect on productivity, signaling inefficient use of resources.

New workers tend to have lower productivity than seasoned workers. Thus, growing companies may experience a productivity lag.

Safety should be addressed. Accidents can take a toll on productivity.

A shortage of technology-savvy workers hampers the ability of companies to update computing resources, generate and sustain growth, and take advantage of new opportunities.

Layoffs often affect productivity. The effect can be positive and negative. Initially, productivity may increase after a layoff, because the workload remains the same but fewer workers do the work—although they have to work harder and longer to do it. However, as time goes by, the remaining workers may experience an increased risk of burnout, and they may fear additional job cuts. The most capable workers may decide to leave.

Labor turnover has a negative effect on productivity; replacements need time to get up to speed. Design of the workspace can impact productivity. For example, having tools and other work items within easy reach can positively impact productivity.

Incentive plans that reward productivity increases can boost productivity. And there are still other factors that affect productivity, such as equipment breakdowns and shortages of parts or materials. The education level and training of workers and their health can greatly affect productivity. The opportunity to obtain lower costs due to higher productivity elsewhere is a key reason many organizations turn to outsourcing. Hence, an alternative to outsourcing can be improved productivity. Moreover, as a part of their strategy for quality, the best organizations strive for continuous improvement. Productivity improvements can be an important aspect of that approach.

There are major some of the system-wide issues that influence the role of productivity and its measurement. These include:

- ✓ global issues,
- ✓ bureaucracy,
- ✓ size of firm,
- ✓ price–demand elasticity,
- ✓ quality economy of scale, and
- ✓ division of labor

Improving Productivity

A company or a department can take a number of key steps toward improving productivity:

1. Develop productivity measures for all operations. Measurement is the first step in managing and controlling an operation.
2. Look at the system as a whole in deciding which operations are most critical. It is overall productivity that is important. Managers need to reflect on the value of potential productivity improvements before Okaying improvement efforts. The issue is effectiveness. There are several aspects of this. One is to make sure the result will be something customers want. For example, if a company is able to increase its output through productivity improvements, but then is unable to sell the increased output, the increase in productivity isn't effective. Second, it is important to adopt a systems viewpoint:

   A productivity increase in one part of an operation that doesn't increase the productivity of the system would not be effective. For example, suppose a system consists of a sequence of two operations, where the output of the first operation is the input to the second operation, and each operation can complete its part of the process at a rate of 20 units per hour. If the productivity of the first operation is increased, but the productivity of the second operation is not, the output of the system will still be 20 units per hour.
3. Develop methods for achieving productivity improvements, such as soliciting ideas from workers (perhaps organizing teams of workers, engineers, and managers), studying how other firms have increased productivity, and reexamining the way work is done.
4. Establish reasonable goals for improvement.

5. Make it clear that management supports and encourages productivity improvement. Consider incentives to reward workers for contributions.
6. Measure improvements and publicize them. Don't confuse productivity with efficiency. Efficiency is a narrower concept that pertains to getting the most out of a fixed set of resources; productivity is a broader concept that pertains to effective use of overall resources. For example, an efficiency perspective on mowing a lawn given a hand mower would focus on the best way to use the hand mower; a productivity perspective would include the possibility of using a power mower.

1.6. The environment of operations and Production systems decisions-a look ahead.

Operation need to consider many product or service factors that affect all activities. The operation should consider the ethical, regulatory, legal and natural environmental concerns in its operation.

Environmental systems standards measure emissions, effluents, and other waste ystems. With greater interest in green manufacturing and more awareness of environmental concerns, ISO 14000 may become an important set of standards for promoting environmental responsibility.

Production system decision is another part that the production operation need to consider. These areas will be tackled in the different chapters of this module. For instance, capacity planning is a key strategic component in designing the system. It encompasses many basic decisions with long-term consequences for the organization. In this chapter, you will learn about the importance of capacity decisions, the measurement of capacity, how capacity requirements are determined, and the development and evaluation of capacity alternatives.

Note that decisions made in the product or service design stage have major implications for capacity planning. Designs have processing requirements related to volume and degree of customization that affect capacity planning.

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