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# Management of Innovation and Product Development

## Integrating Business and Technological Perspectives

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ISBN 978-1-4471-6722-8 ISBN 978-1-4471-6723-5 (eBook)
DOI 10.1007/978-1-4471-6723-5

Library of Congress Control Number: 2015942814

Springer London Heidelberg New York Dordrecht


Printed on acid-free paper

Springer-Verlag London Ltd. is part of Springer Science+Business Media (www.springer.com)

# Preface

What is innovation? Everyone nowadays seems to be talking about this subject. Managers, politicians, journalists, all look to innovation as either a cure-all way to solve problems in society and in the economy or—in other instances—as a threat for the future. On the one side, the popularity of the topic is comforting for those who are engaged in studying the topic or developing it. On the other, it raises the challenge of making sure that innovation is rigorously discussed and professionally managed, instead of using common sense and simplistic reasoning, as it often happens. The purpose of this book is to provide students, researchers, managers, and entrepreneurs with a strong and well-founded understanding of this engaging and fascinating discipline. Specifically, it has the aim of enabling them to understand the dynamics and impact of innovation in an industry, to analyze and define an innovation strategy for a given company, and finally, to manage the development process for new products and services.

Having chosen to cover the spectrum of activities that go from innovation strategy to the design and development of products and services is a characterizing feature of this text. Most other textbooks tend to keep the two aspects apart, covering the former from the perspective of economics and management, and the latter assuming an engineering view. However, it is quite apparent that—in real life—innovation does not follow these academic distinctions at all, and a multidisciplinary perspective is therefore required. Now and again, when visiting companies, talking to academic colleagues, and reading literature, we have noticed how this separation can indeed be artificial and misleading. Trying to cope with the management of innovation processes without knowledge of how products and services are designed from a technical perspective, often leads to a superficial view of the phenomenon. Conversely, adopting a purely technical perspective on product and service design without having a strong understanding of the economic and business forces that shape this effort, often leads to naïve assumptions and unsuccessful outcomes. It may be an imperfect analogy, but a skipper able to safely lead a boat in a long passage must at the same time have strong navigation competencies and be a good helmsman.

The intended readership of the text is therefore—and quite ambitiously—wide. As previously stated, it is aimed at people interested in management and in engineering, in the hope that it will contribute to bridging these two fields. Moreover, it is directed at both academics and practitioners, since it is founded on rigorous research and evidence coming from the field and—at the same time—it provides a number of practical suggestions and insights. We therefore hope that academics may find useful ideas on how their findings translate into practice, while practitioners may understand the reasons that underlie many popular recipes suggested by the professional literature and by consultants.

Concerning its use as a textbook, our experience suggests that the contents are particularly suitable for graduate students in the fields of economics, business, or engineering. Undergraduate students may also benefit from its multidisciplinary perspective, although the scientific depth with which topics are covered might make the book somewhat demanding to be read.

Readers of the book will notice that we have strongly associated innovation to technology. We are well aware that innovation is not only *technological innovation*, and that it can therefore assume many different forms. However, we are convinced that technology—intended in a broad sense—is nonetheless a central enabler to innovation of any kind, and must therefore be adequately covered. Conversely, the book also extensively covers innovation from the perspective of social sciences, in the acknowledgment that it is a social phenomenon indeed, both on the side of supply as well as on the side of demand. This nature of innovation as a jointly social and technological phenomenon suggests that—at least up to a given point—it is invariant with respect to the different disciplines of technology and industries.

Of course, having decided to adopt a multidisciplinary perspective on a topic, as broad as innovation has its own limitations. From the perspective of scholars in economics and management, this can be considered to be a textbook providing the foundations of the discipline. However, not being an advanced treatise, it reports the outcomes and results of the major contributions to literature, but without providing a full analytical and quantitative discussion. From the perspective of engineering scholars, the book reaches into the topic of engineering design processes, but stops at the threshold beyond which the discussion would have been discipline-specific. This can make it a useful complement to traditional and focused engineering textbooks, and will provide students with the understanding that design processes are broadly common to all fields.

The book is thought as divided into four parts. The first chapters of this book consider innovation mainly as an economic phenomenon, and look at it from the high-level perspective of an industrial sector and of society at large. It investigates the role of innovation in business and society, the determinants, the many types of innovation, and its dynamics.

Then, the discussion enters a lower level of analysis, and considers the definition of an innovation strategy for a given firm, as part of its overall corporate strategy. It relates innovation strategy to the most popular approaches to corporate strategy, and then focuses on the management of portfolios of competencies and of projects as the two main levers with which innovation strategy can be enacted.

Subsequently, operational-level activities and the management of product development are debated. The book focuses on issues related to the organization of product development and of the resources involved, to the structuring and management of the product development process, and finally, to the use of project management techniques in the context of product development.

Finally, the book explores individual phases of the product development process and provides readers with the technical tools that can be used in this context to make it happen. It starts from the initial phases of market research and product positioning and—after discussing the issues pertaining to the definition of product requirements and specifications—it leads to the conceptual design or redesign of products or services.

The book purposely does not include a glossary. In our teaching experience, we have noticed that students always and proficiently use Internet sources, such as Wikipedia, to find meanings of terms and concepts. We have chosen not to go against an innovative trend and, therefore, we have highlighted with an asterisk the terms and concepts that could be interesting to readers and for which—upon checking—Wikipedia provides a sufficiently complete and reliable presentation, which makes it appropriate *in lieu* of a glossary entry.

Finally, and as it will be discussed in the first chapter, innovation studies heavily rely on the exploration and interpretation of past cases and events. Most concepts and topics are therefore illustrated by using short examples coming from real cases that have occurred in history. We have chosen not to provide fully fledged case studies, but simple pointers to these stories, each time extracting the interpretation that is relevant to the topic being discussed. Examples come from fields that readers should be familiar with, such as automobiles, consumer electronics, information technology and energy, so that each example may be readily understood thanks to personal experience, and without having to provide a thorough technical explanation. We have made this choice for three reasons. First of all, to reduce the size of the book and make it quicker to read. Second, to show readers how phenomena that have to do with ordinary life in the contemporary world are impregnated with topics relevant to innovation management, and can therefore be interpreted through this perspective. Finally, in an educational context, lecturers may use each of these examples as a starting point for developing student assignments. We have observed that this approach is very helpful for students, who can personally experiment the work of collecting information and data on innovation-related phenomena and of deriving interpretations, ultimately acquiring stronger analytical skills and competencies. We are conscious that the examples provided will naturally tend to age, making them less immediate and meaningful to students' memories and experiences. We therefore intend to update these examples in future editions of the text. Moreover, we are developing an online companion collecting business cases and histories and to which the same readers may eventually contribute.

# Acknowledgments

This book results from nearly fifteen years of experience in teaching and sharing the captivating subject of innovation management and product development in different contexts, having taught and supervised projects with university students from engineering, architecture, and business; interacted with scholars in our research activities; consulted and run seminars with managers and entrepreneurs in both established and start-up firms; and cooperated with policy-makers at both regional and national level. We therefore owe the insights behind the book not only to the authors of the huge underlying literature that we have attempted to systematize, but also to the thousands of people who over the years have given us feedback and suggestions, and have confirmed the value of the multidisciplinary approach we adopted.

Special thanks to the colleagues and friends who over the years have built and shared this path with us, and especially Luigi Buzzacchi, Mario Calderini, Gaetano Cascini, Paolo Neirotti, Emilio Paolucci, and Giuseppe Scellato, along with our numerous colleagues from The Design Society, the Alta Scuola Politecnica, and the I3P Incubator.

Finally, we thank our spouses and our children for their support and understanding throughout the long process of writing this book.

# Contents

# Chapter 1
# Innovation in Business and Society

If we pause for a second to look at our daily lives, and try to compare them with the lives our parents and grandparents led, the differences are striking. Just about any activity we tackle, be it in our family life, at work, or when relaxing, is quite different from previous generations and benefits from completely new technological means. Moreover, if we take a glimpse into products and services that are currently being developed, the future pace of change shows no sign of slowing down. Innovation, and the underlying progress of technology, is therefore highly relevant to our lives as consumers.

Innovation is also highly relevant to our lives in business. If we compare the Fortune 100 or Fortune 500 lists of companies over the years, we find that many current members of these rankings were nothing but small firms, or fledgling startups just a few years ago. At the same time, large and successful firms have dropped off these lists. Innovation is certainly one of the key factors that are responsible for such dramatic changes, and it is therefore unsurprising that the attention that managers pay to innovation is quite high.

At a broader level, economists tell us that economic growth and innovation are strongly intertwined. Robert Solow, Nobel Prize in economics laureate in 1981, showed that GDP growth cannot simply be explained by looking at growth in production factors (i.e., capital and labor). What also matters is productivity growth (i.e., the economic value created by the same units of production factors), and that progress in knowledge and in technology is responsible for this. Policy-makers are therefore quite keen on understanding innovation and in finding ways to foster it in the countries and regions they are called to administrate.

In this book, we tackle innovation from the perspective of a business manager operating in a specific company. He or she will have the goal of making choices that will ensure success to the company's products, and profitability to the firm as a whole. This perspective is therefore different—and also entails more risk—than that of a government agency whose objective in drafting innovation policy will be to ensure economic success to the firms of a region, but thinking in aggregate terms.

The relatively narrow focus on the management of an individual firm might lead someone to question the very possibility of managing innovation. In fact, it is widely held that innovation implies bringing to life something that did not exist before. So, this appears having much more to do with serendipity, luck, and strokes



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_1

of genius, rather than with the activities one would typically associate with management, such as planning and organizing. However, as Mark Twain famously said, "*The past does not repeat itself, but it rhymes*". The discipline of Innovation Management somewhat follows this witticism by the great American novelist, and is based on the idea that—by studying past cases occurring in industry, from ocean clippers to light bulbs and from automobiles to digital photography—the patterns that are uncovered might shed some light on current and future transitions, such as the advent of cloud computing and the diffusion of electric cars. This insight on the future, fuzzy as it may be, might therefore be used as a foundation for a rigorous and systematic management of the innovation process in a firm.

The study of innovation management is first of all rooted in an adequate understanding of technology. In fact, we adopt a somewhat strong hypothesis that, while not all innovations are strictly technological innovations, technology will have an enabling role to innovations of any kind.[1] At the same time, it must be acknowledged that innovation cannot be fully understood from a purely technological perspective, and also requires a deep understanding of economic, organizational, and social elements. In fact, if one looks at the side of supply, technology is the outcome of social interaction in companies and supply chains. Symmetrically, if one looks at the side of demand, innovation happens when a market emerges in society, and this market will be made up of customers willing to use and buy goods and services based on a technology at a given price. In the end, we view innovation to be a social phenomenon and a managerial activity whose object is tightly—though not exclusively—related to technology.

This social nature of technology and innovation suggests that many of the related phenomena will be invariant with respect to the different branches of technology and the many industries in which economic activity is articulated.[2] Though this might at times seem strange to those who have been trained in a specific technical field, it implies that the main concepts of innovation management are applicable—at least up to a given level—to any field of technology and to any industry.

## 1.1 Defining Innovation

Defining innovation is not trivial. The Merriam-Webster dictionary provides two definitions. One is "*a new idea, device, or method*", while the other is "*the act or process of introducing new ideas, devices, or methods*". The two definitions are somewhat different, with the former centered on the new artifact, and the latter on its introduction. In Innovation Management literature, it is this latter definition that

[1]For instance, think of the role of complex booking systems based on revenue management* techniques in the airline industry, which have enabled significant business model innovation.

[2]As an example, the strategies followed by personal computer makers in order to make their proprietary solutions standard might be of some teaching to electric car makers. Similarly, methods used to manage software development projects can be applied to the design of industrial products.

matters, and the focus of innovation therefore is on the impact that new ideas, devices, or methods can have on business and on society at large. This definition allows pointing out the differences between innovation and other related terms such as "*discovery*", "*invention*", and "*product development*". In first approximation, it is possible to propose the following definitions:

- **Discovery**. Discovery is the act—or the achievement—of uncovering something previously unknown. Discovery is the usual outcome of the activity called science. Science* has the aim of creating new knowledge on natural or social phenomena and—unsurprisingly—the main indicator with which individual scientists and scientific organizations are evaluated, is the number and quality of publications reporting on this knowledge. Discovery therefore produces scientific knowledge, by building new results on top of prior knowledge of the same kind.[3] This is evident by glancing at any academic paper, and observing the central role that authors give to references to other previous works. When working on their research projects, scientists are drawn to discovering and understanding phenomena at the highest possible level of abstraction and—at least in principle—they are not immediately concerned with the applicability of their findings. Of course, a scientist who studies the impact of a given protein complex on the development of cancerous cells will probably wish that her results might one day lead to a cure for cancer. However, the two activities of discovering the impact and developing the treatment are not only quite far away in time, but conceptually very different from one another. Although this point is often debated, one could argue that—should science always be concerned with and directed to applicability—this would probably limit its progress.
- **Invention**. Invention is the act—or the achievement—of devising a solution to a problem. Invention is the typical outcome of the activity called technology* (from the ancient Greek *techné*), which has the aim of ideating and validating *artifacts*. The term "artifact" is very broad, and encompasses material entities (i.e., an airplane) as well as immaterial ones (i.e., a business process), simple entities (such as a vase) or complex ones (such as a spaceship). A technologist might in principle wish the broadest possible applicability of his invention but, in practice, his concern will be to achieve a desired level of performance in a specific setting. For instance, an inventor dealing with corkscrews will typically try to develop an improved tool for pulling corks out of wine bottles, and will not be likely to attempt the development a generic tool for separating any two objects that are wedged into each other. Technologists carry out their activity by using both scientific knowledge and technological knowledge. For instance, it is obvious that an engineer designing a new elevator will benefit by being familiar with Newton's laws of dynamics. However, she will also use a host of other empirical knowledge elements that a scientist would not normally care about,

[3]Isaac Newton famously used the metaphor of scientists as "dwarves standing on the shoulders of giants" to express this idea.

but are critical to developing artifacts that work effectively and safely when placed in the hands of users.

- **Innovation**. Finally, innovation can be defined as the "economic exploitation of an invention" (Roberts 1987). In simple terms, society moves from invention to innovation when an invention is marketed and bought. This means that a producer is able to develop an artifact that will give customers a utility that is greater than the cost of production, and to offer it at a given price and in such a way that customers will effectively be able to recognize such value. The difference between invention and innovation is much deeper than usually thought. In fact, most people mistakenly credit the invention of important artifacts not to the (often many) inventors who have progressively and incrementally worked on them, but to the innovator that first managed to create a successful business.[4] In some instances, innovation may occur decades after the original invention, and in completely different environment and circumstances.[5] Innovation is then followed by *diffusion*, which is the process with which the market progressively adopts the new technology and makes it mainstream. Depending on the industry, diffusion can take from months (e.g., mobile messaging applications) to decades (e.g., industrial machinery). This wide variation in the time required by diffusion makes the financial attractiveness of innovations in different industries widely dissimilar.
- **Product development**. Product development is the name given to the business process that a company performs to deliver an innovation to the market. When compared to other business processes, such as payroll, purchasing, or production, product development shows some striking differences. Not only its duration is measured in months and years instead of hours or days, but it is also highly interfunctional, interdisciplinary, and knowledge intensive. This raises significant managerial challenges, which will be at the heart of a number of future chapters of this book.

The study of Innovation as an economic phenomenon dates back to the work of a number of pioneering academics, among which we can especially remember

[4]Many examples can be mentioned. One of the probably most striking ones is the incandescent light bulb, whose invention most people would credit to Thomas Alva Edison. However, Edison did not really do so, but was the one who improved prior artifacts invented by many predecessors, and made the light bulb commercially viable. Edison blended technological and business acumen. First of all, he managed to identify beachhead markets to which he could direct his earlier and still underperforming products, such as ships, industrial facilities and wealthy individuals (Jonnes 2004). Then, he followed with street lighting and, finally, offices and households. Even more, he deeply understood the systemic nature of his invention and the need to develop complementary goods, such as generators, enabling the market to adopt his technology as a complete solution. Similarly, neither Henry Ford nor Bill Gates invented respectively the motor car or the personal computer. However, it is thanks to them if these artifacts have effectively become widely diffused innovations.

[5]For instance, Stirling engines* (a special type of steam engine) were invented in the eighteenth century and have hardly ever been used in practice. However, they are now being considered as interesting solutions for generating electricity from the heat obtained in solar concentration panels.

Joseph Schumpeter* (1883–1950), who is commonly considered to be the founder of economics of innovation. Economists had always been aware that technology and innovation had an economic impact, but mostly considered them as *exogenous* to the economy, i.e. something similar to a disturbance, that could at most be studied from a purely technical perspective. Schumpeter was the first to acknowledge that technology and innovation were instead *endogenous* to the economy, i.e. both determined by economic factors and impacting on the economy.[6] One of the main contributions by Schumpeter (in the Theory of Economic Development 1911) lies in the study of the actors driving the phenomenon of continuous change that we call innovation:

- **Innovators–entrepreneurs**. Alexander Graham-Bell, Thomas Edison, Bill Gates, Mark Zuckerberg, and Elon Musk are typical examples of innovators–entrepreneurs. These individuals are able to merge technical knowledge with business insight and to introduce dramatically new solutions to the market. Thanks to their efforts, they often lead small startup firms to business success and to dominance of the new industries they spawn. Dealing with these cases, Schumpeter introduced the term *widening innovations*, to emphasize the newness of related products, industries, and markets, and described the phenomenon as a "*gale of creative destruction*" that impacts past economic entities and establishes new ones.
- **Large firms**. A few years later, Schumpeter noticed that large firms too engage in innovative activity, and commit considerable labor and capital to improving products, processes, and services. Also in our days, large companies in industries such as automotive, aerospace, and pharmaceutical invest substantial resources in this type of activity. The nature of these improvements is significantly different from above, since the aim is not usually to generate completely new solutions, but to incrementally improve existing ones. One could debate on whether "minor" improvements should be considered as innovations or not. However, if we do follow the previous definitions, even a minor improvement of an existing product will be an innovation (albeit small) if it has an economic impact of some sort. Schumpeter aptly termed these *deepening innovations*, to emphasize their incremental nature.

After Schumpeter, the debate on the types of actors involved in creating innovation has continued. Nowadays, at least two other categories have become important.

- **Networks of firms**. (or *ecosystems*). In recent years, technology has become ever more complex, making it difficult for a single firm to master all the

[6]The exogenous or endogenous nature of phenomena leads economists to interesting choices in their fields of study. For instance, it is obvious that climate and the weather impact the economy, but economists have only recently started studying these phenomena, i.e. since it has been recognized that climate change is likely to be determined by human activity or, in other words, that it is endogenous to society and the economy.

competencies required to develop modern products. At the same time, ICT (Information and Communication Technology) has provided companies with unprecedented means to cooperate with one another and coordinate joint activities. Thanks to these two trends, more and more innovation is being created by groupings of complementary actors that include the innovative startups and the large firms identified by Schumpeter, together with customers and suppliers, and including universities and research centers.[7] This approach to innovation is often structured around the concept of *Open Innovation** (Chesbrough 2003), a term that highlights the fact that innovation occurs beyond the boundaries of an individual company.[8] These groupings are sometimes related to a focal firm, which comes to act as the coordinator of its *ecosystem*—a concept that extends the traditional concept of supply chain, to include customers, suppliers, and complementors. In other cases, the grouping can be wider and include multiple complementary or competing firms. If this type of grouping is associated to a given geographic location, one can talk about *local innovation ecosystems*, or *technology clusters*.[9]

- **Customer co-creation**. In recent years, a number of firms has experimented with a stronger involvement of customers in the innovation process. Instead of supplying finished products and services, firms can limit themselves to providing semi-finished products or platforms that customers can easily use to suit their own specific needs (Ramaswamy and Gouillart 2010).[10] The consequence is that, if one looks at the final product, customers assume the role of innovators. Of course, the firm too can be considered to be innovative, given the change in the underlying processes and business activities that enable customer co-creation.

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[7] Apple Computer is, as of 2015, one of the world's largest firms by market capitalization. However, it is a relatively small firm in terms of employment. Its success is mostly due to its capability of directing the innovative effort of a complex ecosystem of suppliers (e.g., component manufacturers who develop new products specifically for Apple) and *complementors* (e.g., application developers). Similarly, many Internet companies like Facebook innovate by providing a platform on which other companies (e.g., games developers) can deliver innovative products and services. Finally, many large companies, such as P&G and pharmaceutical companies have recently decided to reduce their internal R&D expenditure, and to look for greater cooperation with other entities that may already have developed solutions to relevant problems, or have the competencies to do so quickly.

[8] Open Innovation is sometimes and mistakenly equated to Open Source*. The latter can be considered to be a special type of the former, since Open Source solutions are typically developed in an extremely distributed and non-hierarchical way. However, the way with which intellectual property is dealt with in Open Source is very specific to its philosophy, and does not apply to all forms of Open Innovation.

[9] A well-known example is California's Silicon Valley, an area that since decades has been home to thousands of large and small firms, together with complementary actors who have specialized in serving the needs of the cluster (e.g., patent attorneys, venture capitalists, etc.).

[10] For instance, a paint maker can provide customers with primary pigments and a colorimeter, and leave them the task of blending the colors to achieve the desired shades. Similarly, the diffusion of technologies such as 3D printing and open source electronics is likely to greatly boost the innovative role of customers in the fields of small-scale manufacturing and automation.

Innovation can be of many different types, and a detailed discussion on this topic will be provided in the following Chap. 3. At this point, it is however possible to introduce some popular definitions on types of innovation, though these are not rigorous enough to view them as a proper classification. A major distinction can first be drawn between *product* and *process* innovation, the former being the innovation of products and services that are sold by a company, and the latter being the introduction of new operational methods and tools that change the way a company operates. It is quite obvious that this distinction mainly refers to the perspective one takes and not to the innovation per se. The same microwave oven might be a product innovation for the company that makes them, but a process innovation for the restaurant that adopts it. In addition, literature often uses the term *organizational innovation* for process innovations that have a strong immaterial content and that—rather than changing the technology used by a company—modify the way it operates its business processes. Examples of such innovations can be pure methods or business practices (e.g., Lean Production and six-sigma) or technological artifacts that have a strong impact on the organization (e.g., an ERP system). Finally, a major type of innovation is nowadays constituted by *business model innovations*. This term refers to innovations that introduce a new way to conduct a business, its relationship with its customers and value chain, its revenue flows and cost structure. Business model innovations are often cited when talking about Internet companies,[11] but can apply to other industries as well.[12]

## 1.2 Risk and Reward in the Innovation Process

In very simple terms, it is possible to link discovery, invention, and innovation/product development as in the following Fig. 1.1. The linear model of innovation that is represented here is quite simplistic and is often challenged by

[11]For instance, we can say that a company like Google owes its success to the business model innovation introduced in the Internet industry (in pills, making companies pay for the search results given to users, who instead use the service for free), and not only to the process innovation they have introduced in the search process thanks to sophisticated algorithms. Similarly, Facebook is built on a business model innovation in which users freely access a platform, occasionally pay for additional services provided by complementors (e.g., games developers), while Facebook profits by sharing revenue with them, as well as by advertising.

[12]For instance, Dell Computer has been an important innovator in the computer hardware business by selling directly to customers and assembling computers to order. We can safely say this is a business model, and not simply a process, innovation, because of the change of upstream and downstream relationships. Similarly, low-cost airlines such as Southwest and Ryanair have introduced what we can define as business model innovations, because of the way they overturned traditional revenue flows and cost structures. For instance, meals and baggage handling have become a source of revenue instead of a cost. Sometimes, and with significant controversy, the same has happened for airport fees, thanks to the choice of flying to under-used airports owned by public authorities, who have been persuaded to subsidize flights to stimulate local tourism.

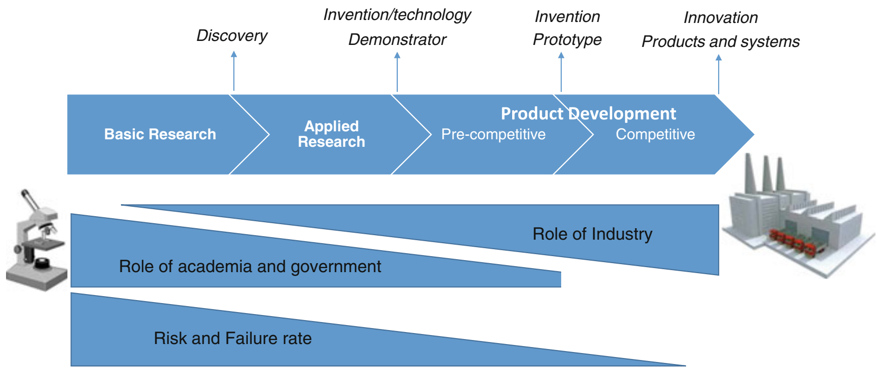


**Fig. 1.1** A simplified "linear" process of innovation

scholars. Authors such as Kline (1985) and Edgerton (2004) have developed more complex models, showing how the innovation process is not really linear, and exhibits many relationships of iterative nature. However, for a first explanation of the phenomenon, the linear model can work fairly well.

Starting from the upstream phases of the model, the activity responsible for discovery is called *basic research*, where basic means it is not directed to a specific application. The activity that leads to invention of a new technology is instead termed *applied research*. The practical deliverable of this phase is generally a *demonstrator*, which is an artifact whose purpose is simply to show that the invention is technically viable. Demonstrators are usually very far from commercial products. At this phase, the main focus is technical and rests on showing the viability of the individual technology per se. Attention paid to potential application areas and target markets is still limited, and the same goes for choices related to complementary technology.

When moving into product development, the focus shifts quite dramatically, since the firm will start dealing with commercial attractiveness (thus defining price) and industrial viability (thus defining cost and margin). This also implies dealing with seemingly menial and often neglected aspects such as usability, safety, manufacturability, logistics, product certifications, writing users' and field service manuals, and so on.

It is customary to split product development in a *precompetitive* and a *competitive* stage. The discriminating element is that the former stage leads to *prototypes* that do not have commercial value (i.e., they cannot be sold), while the latter leads to the actual product that will be launched on the market. A prototype is clearly different from a demonstrator, because the focus is no longer on an underlying technology, but on the features and technical choices that the actual product will incorporate.

Looking at Fig. 1.1, one understands that the innovation process is not only quite lengthy, but also highly risky, especially in its earlier phases. One can therefore wonder which economic actors might bear the effort of investing in the activities represented here. Given the risk and time involved, it is fairly obvious that private sector companies will not usually finance the entire process, and especially its upstream phases, which are riskier and further away in time from providing economic returns. This clearly represents a *market failure**, in which governments are called to step in and provide public funding of the activities that private actors would not invest in. The debate on public–private relationships in the innovation process is a very strong one, but no fervent proponent of economic liberalism would ever suggest that the State should completely withdraw from the field. Besides the fact that the innovation process would simply stop working, it would probably be socially undesirable to have private investment cover the early phases of the innovation process. In fact, firms would make very strong attempt to keep the knowledge generated confidential, and this would lead to a huge duplication of effort. Conversely, public funding of research is usually considered to be more efficient, because it brings the knowledge generated in the public domain. This allows researchers to drive science forward by incrementally building on top of each other's results, and allows companies to freely use such results for the purpose of inventing and innovating. Therefore, most countries throughout the world support the early stages of the innovation process by direct or grant-based financing to universities, research centers, and also companies.

Governments usually have a direct role down to the so-called *precompetitive* phase of product development, whose end-products are prototypes that do not have commercial value. They do not usually act in the last phase of product development since—at this stage—the time required to recover investments is shorter, risks are lower, and markets are therefore usually able to work properly. Moreover, it would be questionable for a government to finance product development activity for commercial products. This would distort competition both within the country (i.e., subsidized producer X would be favored over another producer Y) and in international trade (i.e., producers of a subsidizing country would be favored over the other ones). In fact, this practice is usually prohibited by international agreements, such as the ones promoted by the WTO (World Trade Organization). This general rule does not mean that governments cannot have a strong impact on this phase too, provided they act in roles that do not have to do with direct financing:

- **Regulators at large**. In general, governments can provide an economic and institutional environment that supports or hinders innovation. Taxation, labor and bankruptcy laws, access to justice, etc., have an impact on all firms that operate in the economy, but especially on the ones that invest in innovation. In fact, a favorable environment can increase the "upside" (i.e., the potential returns on the investments made, if successful) and lower the "downside" (i.e., the loss of value, if unsuccessful). Moreover, a dynamic and highly competitive economy will be likely to increase demand for the products and services that are being proposed by innovating firms. Finally, governments can provide generic infrastructure, such as highways and telecommunication networks that lowers the cost and increases the effectiveness of business activities, thus making it easier for private firms to invest in innovative projects.

- **Specific infrastructure**. The diffusion of many innovations relies on infrastructure that is complementary and specific to the innovation. A powerful telecommunications infrastructure can be a tremendous support to video-on-demand services, just like curbside recharging outlets may be highly beneficial to the diffusion of electric cars in urban areas. Government may consider the infrastructure to a public good, and therefore commit resources for its development. At times, this choice may raise two objections. One is related to the fact that the use of public money must be justified by a positive return for society and not only for producers of a complementary good. The second objection is that the development of a specific infrastructure may not be *technology neutral*, i.e. it may support the diffusion of one technology and lead to the demise of a competing and socially equivalent one. This would benefit some firms at the expense of other ones, and would also entail the risk of determining the adoption of a technology that may ultimately not be the best. For instance, a government-funded plan for a network of recharging stations for electric cars will hamper the diffusion of hydrogen-powered vehicles.
- **Regulators with respect to standards**. Governments can at times dictate to industry the features that products must have, with the purpose of increasing social welfare. Defining *standards* for car safety, environmental impact, biodegradability of shopping bags, and telecommunication protocols, can have a strong impact on the innovation process. First of all, it creates a "mandatory market" for goods with innovative content, thus providing an incentive for companies to invest. Moreover, it can lead companies into adopting specific technical solutions (which—as stated above—might be a double-edged sword). Finally, as it will be discussed in later chapters, government-mandated standards can prevent firms from carrying out strategic actions that could lead to unwanted monopolies.
- **Customers**. Governments spend very large amounts of money to provide public services such as defense, health, public transport, and so on. Some countries (originally the USA, but the idea is recently spreading in the EU too) have policies, broadly termed *Public Technology Procurement* (PTP), with which they reserve part of these financial resources to the purchasing of innovative goods and services. Aside from providing citizens with better public services, this creates a strong demand-side incentive to innovation. In fact, the government can easily determine a sufficiently large demand to entice firms into developing innovative products. If the government is also an informed and shrewd customer, these firms will have to comply with demanding levels of price and performance. This raises the likelihood that, later on, these firms may successfully "spill over" these innovations in the private market. Compared to supply-side incentives for innovation (e.g., grants awarded to companies making project proposals), PTP has the advantage of giving the prize to those who are able to deliver, and not simply to make attractive promises. By creating a

real—though initial—market, PTP also leads companies much closer to being able to propose their innovations to the broader market.[13]

When dealing with the downstream phases of the innovation process, public intervention decreases and private entities take the risk and the rewards connected to the financing of innovation. In general, due to the risk involved, firms will not fund innovation through debt. At the most, debt will be used to finance infrastructure (e.g., plants and equipment) or working capital, when demand for the innovation is starting to grow.

Therefore, innovation is generally funded through equity. In the case of established firms, equity can come from the use of retained earnings that managers dedicate to projects whose purpose is the exploration of future growth areas. In the case of startup firms, equity will typically come from *business angels* and *Venture Capital* (VC) funds. The former are wealthy individuals who invest in very young startup companies and, besides the money, usually provide part of their time, professional experience and networks to support the growth of the investee companies. Venture Capital funds, instead, are run by professional investors who lead substantially larger financing rounds (from around 1 million Euros for *early stage* funds, and up to tens of millions of Euros for *expansion* funds), with the objective of exiting their shareholding for a substantial profit after a limited number of years. Given the high risk involved in startups, VC funds target an extremely high return on investment on each deal, knowing that this return will effectively be achieved only by a small minority of their shareholdings. However, by averaging the few significant successes with some minor achievements and a high number of failures, the fund will tend to deliver—in aggregate—a satisfactory return to its investors.

Risk and uncertainty, which are inherent to the innovation process, lead to a number of effects that have the desirable potential of stimulating the process itself. First of all, the risk of failure makes the process selective and competitive. Individuals and companies engaged in the innovation process will go at great lengths to propose new, alternative and improved solutions, thus creating a very wide experimental arena in which the most promising solutions may eventually become successful. If this essentially Darwinian process performs as it should, society benefits since, due to the same uncertainty, it would not be possible to pick the best solution ex-ante.[14] Moreover, even if an enlightened decision-maker were able to do so, lack of competition would probably not create enough incentives to

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[13]In fact, many innovations of common use, from the Internet to GPS, to the popular robotic vacuum cleaners made by iRobot, were originally developed as military technology.

[14]The reference to Darwin has not been made by chance, since the innovation process is based on a very similar mechanism of experimentation, recombination, and selection. In fact, economics of innovation is tightly connected, from an epistemological perspective, to the heterodox school of evolutionary economics. As a side note, innovation economists are well aware that technological progress is somewhat brutal and irresistible, but this does not automatically create a connection with strict economic liberalism and *laissez-faire* policies. For example, an economist of innovation may recognize that e-books and music streaming services are supplanting the traditional media distribution industry. It is likely that she will dismiss suggestions to use public funds to support the

fully develop that same promising solution. Secondly, the selection process will cause firms espousing a losing solution to fail or shrink. This improves the potential returns for the winners, who will gain market share. At the same time, it also creates an important knowledge spillover effect. At least part of the employees being laid off by a losing company are likely to be hired by a winning one, taking know-how and experience with them, and thus enriching the latter even further.[15]

The role of risk in the innovation process might however be difficult to appreciate as a positive one. In many cultures, both at national and at corporate level, failure is perceived as a very negative outcome. A failed project or a failed company might translate in a broken career, respectively, for the manager or the entrepreneur, and this might greatly reduce the incentive to pursue an innovative but risky initiative. In some cases, public authorities may also step in and support firms that risk shutting down their operations because of obsolete technology or business models. By propping up jobs instead of supporting the jobless, this may inadvertently lead to hindering the growth of stronger and more innovative competitors, and taking away an incentive from them.

## 1.3 The Social Impact of Technological Innovation

While technological innovation is generally considered as a desirable phenomenon, it does not only create positive effects. Anyone engaged in this field must be aware of this issue, especially because negative effects can be quite significant. The debate on the negative—though generally unwanted—side-effects of technological progress has started since the first Industrial Revolution, with the Luddites' protests against mechanization of the textile industry. With the advent of nuclear power the debate has become stronger, with the realization that our society had, for the first time in history, created a tool with the potential of *irreversibly* changing the fate of humankind and of our planet. This discussion is clearly very broad, and this book cannot but point out just a few main elements.

A first element of this debate is concerned with the impact of technological innovation on employment. The most significant product innovations have the potential of disrupting established companies, and to lead to the birth of new industrial sectors, which are likely to require a differently educated workforce (e.g., think of the impact of telephones on telegraph companies). Process innovations too have the potential of determining what is usually termed *technological displacement** (e.g., the impact of the personal computer on professional typists). The worry

(Footnote 14 continued)

industry in crisis as completely useless, but may recommend actions aimed at reconverting its assets to other markets.

[15]Well-known technology clusters such as the Silicon Valley are characterized by a very high "churn rate" of companies and jobs, which leads to the collective growth of the entire system.

that technological innovation might determine unemployment is probably as old as technology itself. However, history tells us that this impact is limited to the short or medium term, since humankind always finds new needs to be satisfied through economic action, and this leads to the growth of new companies and the creation of new jobs. This said, the short-term impact on the people involved is undeniable and has to be managed, usually by public intervention, since the new and emerging jobs are likely to require a skill set that is different from the one that characterized the displaced companies.

A second element of the debate relates to the *power* of technology. In the words of philosophers such as Martin Heidegger* (1889–1976) and Hans Jonas* (1903–1993), contemporary technology is no longer a tool that weak humankind uses to shield itself from a hostile nature, but has become a powerful force that can shape the world. With technology, man has a very powerful instrument that can be deployed to many means, and in ways that can lead to long-term and far-reaching—if not even irreversible—consequences.[16] Therefore, it is imperative for managers involved in innovation to consider such consequences.

The third element relates to humankind's capability of properly using technology, whatever might be meant by the word "proper". Following two contemporary philosophers, Andrew Feenberg* and Umberto Galimberti*, it is delusional to think of technology as a neutral tool in the conscious hands of rational humankind (a representation that—if true—would somehow allow technologists to ignore the debate). According to these authors, "conscious use" of technology is a myth, because understanding what an appropriate use of a given technology is, will always require experience and time. In the meanwhile, human beings will tend to follow the values that are intrinsic to technology itself, which are effectiveness and efficiency ("if it can be done, why not?").[17] This problem is aggravated by the fact that people let themselves be *identified* by the tools they use.[18] In other terms,

[16]Think of nuclear waste or (though the debate is still ongoing) of the potential impact of GMO crops on biodiversity.

[17]The phenomenon can be observed when modern technology is introduced in a primitive society, or when technological progress is very fast. As an example for the former case, when refrigerators have been introduced to primitive societies accustomed to hunting, this has often led to obesity and drunkenness, since people do not know how to properly manage a constant supply of food. Concerning the latter case, consider genetic screening of embryos. Aside from the controversies associated to the nature of embryos ("is it a human being we are discarding?"), the problem is related to the objectives. The technique was originally intended to avoid giving birth to babies with genetic diseases. However, when technology will allow it, and given the choice, what parents will not try to use it to have better looking and more intelligent babies too? And how is society going to make sure that this will not develop into fully fledged eugenics, as in Huxley's "Brave New World"?

[18]A caveman with a club is not simply a stronger man than his peers. According to his tendencies, he might become a man of order who protects the village from enemies, the village chief, or a mugger. In more modern times, smartphones profoundly change the habits of their users and their attitude with respect to their equals. Companies know this phenomenon quite well, and marketing effort often amplifies the effect.

technology shapes human behaviors as much as humans can pretend they can rationally and consciously determine the application of technology.

This discussion is of course relevant to philosophers and social scientists. Is it relevant to managers too? The answer is positive, since the business impact of these issues can be quite significant. First of all, they are of immediate relevance to business ethics* and to Corporate Social Responsibility*. Secondly, the neglect of such issues can have major impact on profitability. If, in fear of its potential environmental or social impact, society does not trust a potentially far-reaching innovation, it might stop or slow down its adoption, ultimately reducing the return on investment for the firms that are proposing it.[19]

Finally, unforeseen consequences of a given technology can have dramatic consequences because of *product liability**. Most legal systems affirm the principle that producers are responsible for defects in the products they market and for the related consequences. In the case of minor innovations, this liability is commonly connected to mistakes made when designing or producing the product, and the management of liability does not generally raise significant problems.[20] However, what happens in the case of major innovations, when the product is new to the world and not enough is known about potential side effects[21]? This issue is highly controversial. On the one side, customers have the right to be shielded from dangerous products. However, should producers be fully responsible for any unforeseeable consequence of their technology, this additional risk would likely lead them to the decision of not investing if not in minor innovations based on proven solutions.[22]

[19]Coming back to the example of GMO crops and food, European markets have long resisted adoption. Even if, in the end, they might end up accepting this technology, what is the financial impact of this delayed adoption?

[20]There are cases in which product liability can raise complex issues even for technology that is not particularly innovative. For instance, a pharmaceutical company might decide to withdraw a socially desirable product, such as a drug, if its profitability is not high enough to offset the potential liability that might emerge, because of rare but highly damaging side effects on particular customers.

[21]Dramatic and well-known examples of such phenomena are tobacco smoke and asbestos, which have led to countless casualties and decades of debate between the first detection of the problem, and legislative action restricting their usage.

[22]In order to cope with this trade-off, the EU has introduced a rule termed "Development Risk Clause". The Clause states that "*The producer shall not be liable [...] if he proves that the state of scientific and technical knowledge at the time when he put the product into circulation was not such as to enable the existence of the defect to be discovered*" (Directive 85/374/EEC). However, this solution is not without problems. Besides leaving consumers with residual risk, firms are effectively taken away incentives to work on product safety, since ignorance on side effects shields them from liability. This leaves the advancement of the state of the art on potential dangers of new technology to public authorities alone, who might not be able to develop or access enough knowledge on the subject.

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# Chapter 2
# Technological Knowledge and Organizational Learning

Innovation and knowledge are intimately connected. Firms and individuals are able to innovate thanks to the knowledge they possess, while the process of innovation they are engaged in, can—in turn—influence their knowledge. As we will soon see, this emphasis on knowledge has led students of innovation to develop a very specific perspective on the nature of firms, based on knowledge assets and learning capabilities. So, the first point to be covered is the definition of knowledge and its role in technology and science.

## 2.1 Knowledge in Technology and in Science

The nature of knowledge* is a central topic in many fields, such as philosophy, psychology, sociology, and economics. Providing a single definition is probably next to impossible. Moreover, the perspectives from which knowledge has been studied vary significantly, with a debate in the Western world that is split among empiricist and rationalist approaches, and an Eastern perspective in which rationality and emotion are blended under the concept of "whole personality" (Nonaka and Takeuchi 1995).

For the time being, we can follow the traditional "tripartite" definition, of knowledge as a "*justified true belief*", or as a "*belief that is in accordance to the facts*".[1] Given the aims of this book, we can avoid attempting a philosophical discussion on the nature of knowledge. Instead, it is certainly useful to define some characterizing features of the different forms of knowledge, since this is highly relevant from an economic and managerial perspective.

- **Incorporation in people versus incorporation in capital**. Knowledge typically has to do with people, and we can consider it quite natural to claim that knowledge is "incorporated" in the human beings who possess it. However, it is

[1]However, as Bertrand Russell* (1972–1970) pointed out, the problem is that "*no one knows what a belief is*, *no one knows what a fact is and no one knows what sort of agreement between them would make a belief true*".



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_2

also possible to conceive knowledge being incorporated in a material asset, such as a book, a computer algorithm, or a mechanism.

- **Codifiability versus non-codifiability**. Codifiability means the possibility of representing knowledge through a language (or *code*). For instance, the knowledge required to bake a cake can be expressed in natural language, as you will find in a recipe book, while the knowledge required to run a statistical test can be expressed in a mathematical formula. However, codifiability cannot generally be complete. A recipe usually will retain some degree of ambiguity that can be solved only by an experienced cook (e.g., "how much is a pinch of salt"?) or by using costly equipment (e.g., a precision scale for weighting the same salt).
- **Explicit versus tacit**. Knowledge can at times be easy to articulate and express, and will therefore be said to be explicit. In other cases, articulation of knowledge may be very difficult. Quite often, someone may not even be aware of the knowledge she possesses, let alone find a way to express it to others. This tacit knowledge is inherently non-codifiable and will tend to be incorporated in a person. The only way to transfer it to others will be through a lengthy process of observation and apprenticeship. Therefore, a person may be a very skilled and experienced cook, without being able to articulate the actions and choices he makes when working in the kitchen. Conversely, another person may read a recipe but—lacking the tacit knowledge that is required to correctly interpret it—may not be able to cook a decent meal.
- **Private versus public**. This definition generally refers to whether knowledge is kept secluded within a limited set of people, or whether it is given to the public domain. However, it should be noted that this terminology leaves some ambiguity regarding the *economic* definition of knowledge as a private or public good.[2] For instance, the information in a patent is public knowledge and is a public good, because anyone can access it at any time and use it *as information.* The invention itself, however, is not a public good, because the same patent excludes anyone but the assignee of the patent (or its licensees) from the right of making any commercial use of it.

With these definitions in mind, it is now possible to describe four main forms of knowledge.

- **Factual knowledge (or "know that")**. An example of this kind of knowledge is a record of the results of a scientific experiment, or of the failures observed in a fleet of vehicles during the last year. This is a very basic form of knowledge, evidently easy to represent and structure, as for instance in a report and/or a database. It is usually explicit, codifiable and simple to incorporate in capital.

[2]In economics, a private good is characterized by the fact that it is *rivalrous* (i.e., consumption by an individual prevents the simultaneous possibility of others to consume it) and *excludable* (i.e., it is possible to prevent someone from consuming it). Conversely, a public good is *non-rivalrous* (consumption by an individual does not prevent simultaneous consumption by others) and *non-excludable* (i.e., it is not possible to prevent someone from consuming it).

This type of knowledge is very close to the basic concept of *information*, but it can be considered as knowledge, because raw information must have been structured and described to some extent, thus making it fall in the definition of "justified true belief".

- **Causal knowledge (or "know-why")**. This is a higher level of knowledge, and is concerned with understanding, or trying to infer, the reasons behind facts. In its quest to explain the way natural phenomena and social courses carry out, science is particularly involved in the creation of causal knowledge. A paper in a scientific journal will typically describe a phenomenon, propose a theory that explains it, and then justify it on rational and logical grounds, analytically, and through empirical evidence. A technologist too will attempt to generate causal knowledge, though in a way that will tend to be situation-specific. For instance, a designer may analyze the database of product failures in vehicles, extract patterns, try to infer the reasons behind them, and maybe trace them back to a specific component of the car. Causal knowledge is relatively easy to codify and to incorporate in capital (e.g. an academic paper, or a technical report written in natural language and making use of mathematical formulae, tables and graphs). When dealing with causal knowledge, a distinction may be made between *empirical* and *theoretical* knowledge. The former correlates observations on the basis of experience, but without yet making claims on the underlying reasons. The latter attempts to explain the reasons behind these phenomena. A cook may empirically observe that boiling water is not hot enough for cooking rice when working in the mountains, but not have a clue about the reason. She may attempt a theoretical explanation, such as "probably in the mountains it's much colder", which may or not be the real one (as a matter of fact, it isn't). Empirical and theoretical knowledge are nonetheless tightly related. Following Poincaré* (1902), it is impossible to draw knowledge from experience "without prior ideas", since it is background knowledge that allows a person to structure, name, and classify observations into knowledge elements.
- **Procedural knowledge**. This is a still higher level of knowledge, and is the one we usually associate with the term *know-how*. Procedural knowledge is what everyone employs to achieve a given result in private and professional life. This knowledge derives from a mixture of schooling, experience and, possibly, innate talent. To a scientist, developing procedural knowledge is not a core objective, but is a useful tool that she will use in professional life, i.e. when setting up experiments, analyzing results, or presenting findings at a conference. To a technologist, whose professional objective is to solve specific problems, the development of procedural knowledge is instead of central importance. In our example, once the designer has developed the causal knowledge that product failure is due to a particular component, procedural knowledge will enable him to redesign the component to improve reliability. Know-how is typically tacit, difficult to codify, incorporated in people and, therefore, naturally tends to be private.

- **Positional knowledge**. Finally, one may not directly own a knowledge element, but know where it is stored, or who possesses it. Even though this is an indirect type of knowledge, *know-who* is indeed very powerful. This is especially true for organizations, where it is not expected that everyone knows everything but, on the opposite, economic value is created by linking together the knowledge elements that are possessed by its many members. To the extent that underlying knowledge can be categorized and classified, positional knowledge is relatively easy to codify and incorporate in capital.

The previous discussion has purposely highlighted a few key differences between technological and scientific knowledge. However, we know from the previous chapter that science and technology are related to one another in the innovation process. One can therefore wonder how this relationship works, and how does scientific knowledge contribute to technological progress.

The issue is not trivial since, following Fleming and Sorenson (2004), the strength of the connection between science and technology varies quite significantly across disciplines and industries.[3] Moreover, the contribution provided by scientific knowledge to technology is not direct, since the objectives for which it has been developed (i.e., providing broad explanations of phenomena) are somewhat different from those of technology (i.e., finding solutions to specific problems). So, these two forms of knowledge can be viewed as complementary to one another.

Technologists, who must to stay close to the requirements cast by a specific situation, tend to operate on a “local search” basis, applying small variations to known solutions. By operating through trial and error, they progressively build a body of technological knowledge based on experience and empiricism. Technology is sometimes represented as a rugged terrain where solutions correspond to the position on the xy plane, and the associated performance to the elevation of the terrain on the z axis (Gavetti and Levinthal 2000). Technological progress can therefore be illustrated as an exploration of the terrain in the dark, in which one progressively looks for solutions having an improved performance. Following this analogy, scientific knowledge can be equated to a relatively rough map of the terrain, possibly not detailed enough as to allow a precise definition of solutions, but able to provide technologists with the “wide picture” they would miss by myopically exploring the terrain step by step. Thanks to this “map”, technologists can therefore work with greater efficiency. When operating incrementally, the map shows the most promising directions along which to search, thus reducing the amount of experiments required. The map can also allow technologists to break loose from “incrementalism” and look for better and globally optimal solutions,

[3]In the case of life sciences, the relationship is very tight, and it is at times difficult to discriminate between activities, actors, and languages. An academic researcher will be likely to have a good understanding of industrial needs, while a researcher in the pharmaceutical industry will routinely read academic papers. Conversely, if one looks at computer science, a programmer engaged in writing code will use a substantial amount of practical know-how, but with a loose connection to the knowledge developed in the academic domain.

even if these are significantly different from traditional ones. Finally, the map can provide organizations with an objective rationale for justifying the continuation or the rejection of projects, from a financial and organizational point of view.

Given that scientific knowledge has to a technologist the same role that a map has to an explorer, we still need to achieve a better understanding of technological knowledge. Up to now, we only have shown that this latter kind of knowledge is tacit, difficult to codify and transfer, since it is rooted in experience. This topic has been amply studied by Vincenti (1990) in his seminal work, based on a deep analysis of the evolution of knowledge in the field of aeronautical engineering. Vincenti's main finding is that technological knowledge is broader than simply "applied science", and can be classified in the following categories.

- **Basic concepts**, such as working principles and common product configurations that can be immediately learned when entering the field.
- **Design criteria and specifications**, such as requirements, technical standards, and regulations.
- **Theoretical tools**, such as mathematical formulae and mathematical models.
- **Quantitative data**, coming from prior experience, or purposely generated through experimentation.
- **Practical knowledge**, deriving from experience, "rules of thumb", and lessons learned from past failures.
- **Design instrumentalities**, such as procedures and judgmental rules shared by the firm or by the wider professional community.

The four former categories can be considered to be explicit and fairly easy to codify, while the latter two are typically of tacit nature. These same categories can be found in about any technological field or industry. However, the knowledge residing within each category will emerge out of the experience gained by solving the problems encountered by each industry and firm, and will therefore be quite specific to them. This specificity raises the issue—that will be covered in the next section—of understanding how differences in knowledge can determine differences in the behavior and the performance recorded by firms.

## 2.2 An Evolutionary Theory of the Firm

Since Schumpeter, economists of innovation have struggled in trying to define the nature of firms as actors of technological change. To them, it was not possible to settle with the neoclassical vision of the firm as an economic agent that, with perfect rationality and full information, observes market demand, chooses production factors (capital and labor) and defines a production function. In fact, economic environments affected by innovation are inherently uncertain and turbulent, and this clashes with the hypothesis of perfect rationality and full information. Moreover, turbulence will likely make competing companies behave in significantly different ways. This too diverges from the neoclassical idea that differences between firms may exist only in the short-term, since less successful firms will quickly imitate successful ones. So, a theory of the firm that satisfies students of innovation should be able to answer the question "why are firms different?"

The question has gone unanswered for a long time, until Nelson and Winter (1982) proposed that a theory of the firm could be developed by observing organizations inside-out, instead of outside-in.[4] Following this theory, a firm can be defined by a *static* and by a *dynamic* view.

The static view posits that a firm can be defined as an *organized association of complementary resources*. Resources are intended as human resources or physical assets that can be acquired at a cost, and who create an economic value that is hopefully greater than their cost. Complementarity means that the economic added value that is jointly produced by resources is greater than the sum of the economic values that would be separately created by each. Complementarity justifies the very existence of firms, i.e. the coexistence of a set of resources in the same organization, instead of the interaction between autonomous entities through market mechanisms. Thanks to complementarity, resources in a firm will generate a combined economic value that is sufficient to cover the fixed costs of the organization (e.g., management, support functions, etc.) and to provide economic returns to its shareholders.[5] Finally, "organized association" means that the firm is able to put these resources to work and therefore ensure the creation of economic value.

The dynamic view builds on the static view, and deepens this concept of "organized association". Here, the organization is not viewed as the simple allocation of duties and responsibilities that one could represent with an organizational chart, but as *a bundle of organizational routines*. As anyone who has worked in a company will have noticed, a wide majority of the work being carried out by employees at all levels is routine, and a large portion of this routine work is performed without having been explicitly defined or formalized. This observation is obvious when workers deal with similar problems all the time (e.g., assembly work, processing accounts payable, etc.). However, it is equally true for employees who daily encounter different problems (e.g., a designer, a medical doctor, etc.) but end up tackling them in the same way, as suggested by experience or dictated by formalized protocols.

These organizational routines define the steps that the firm will follow to reach a given objective and the resources to be involved. Routines can therefore be viewed as the actions that firms enact to "activate" resources and "extract" a contribution

[4]This perspective is coherent with other scholars' views of firms. For instance, Hayek (1945) identified the role of tacit knowledge as a source of competitive advantage, and Penrose (1959) emphasized the role of learning in organizations.

[5]Based on this perspective, management's duty is to respectively recruit and purchase people and equipment, so that the difference between the economic value created and the cost is maximized. In the case of human resources, this does not simply mean recruiting highly effective people, but especially teams that will work well together, and made up of individuals whose salaries are not too high.

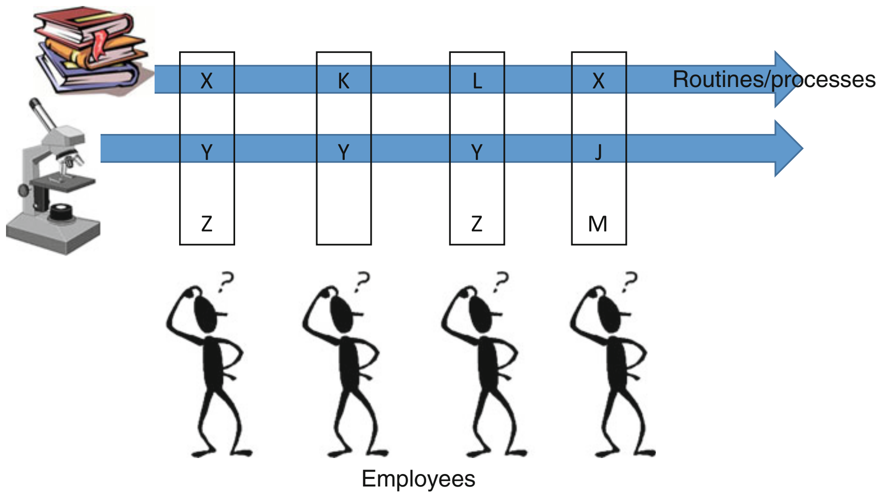


**Fig. 2.1** The firm as a "bundle of routines"

from them, based on the knowledge they possess, thus progressively building up economic value.

Looking at the example in Fig. 2.1, we can suppose that a firm is made up of four people who individually own the knowledge elements represented in the rectangles. We can therefore say X is part of corporate knowledge, not because the company directly "knows" X, but because a routine is in place, that allows the firm to use "X" being provided by its employees. Conversely, we cannot say M or Z to be part of the firm's know-how, since no routine has been set up for using these knowledge elements. Therefore, routines represent a firm's knowledge base, which can be defined as the organized collection of the knowledge elements used by resources involved in routines. A major part of this organizational know-how will be tacit, being based on individuals' tacit knowledge, and because of the informal nature of the routines themselves.

Should an employee with knowledge of X leave, the firm would lose X, but not its capability of using it. Therefore, managers will respond by recruiting a new employee possessing X and integrating her in the appropriate routines (Argote et al. 1997). From the perspective of the employee who leaves the company, she would take out her personal knowledge, as well as the experience of using it within that specific firm's routines. However, it would be difficult for her to join a new company and replicate the routine, since an individual is not likely to have a general view of the routine, and also because the effectiveness of the routine depends on the context. Even if this employee did have a broad vision of the routine, the *ex-novo* replication in the new firm would be difficult, given the different set of resources and routines already in place there. This explains why individuals' performance within organizations is said to be *institutionally specific* or *idiosyncratic* (Groysberg et al. 2006). In plain terms, an employee's performance will depend on the complementary resources that are present in the company, and on the routines within which he works. An employee who performs well in one firm may therefore prove a disappointment if hired by another firm, and vice versa.

So, we can conclude that there is a very tight connection between what a firm is, what it does, and what it knows.

The concept of routines is broader than that of *business process**, which can be defined as a routine that has been recognized and formalized. Routines mostly *emerge* by trial and error, and because of the effort the organization spends in finding effective and efficient ways to reach its objectives and to deal with the problems it encounters.[6] This search process will not lead to an optimal solution but, rather, to a *satisficing*[7] one. As a matter of fact, there can be nothing like an optimal routine, first of all because the iterative process with which a firm looks for new ways of doing things will slow down when the performance reached is "good enough". Second, the very concept of optimality is impossible to define, since the appropriateness of a routine is highly specific to the firm itself, i.e., to the market, technology, workforce, and economic environment the firm operates in.

Routines are beneficial to firms, because they represent an effective, efficient, and predictable way of working, in a given environment. However, if the situation changes, the firm will have to adapt its routines and possibly its pool of resources to regain a satisfactory level of performance. If the change in the environment is limited, the new desired state will likely be close to the previous one, and it will not be difficult to achieve it. However, if the change is significant (e.g., if a completely new technology emerges, or if the government introduces a sudden change in regulations), the firm will find it quite difficult to adapt and regain a satisficing state. The term *organizational inertia** is often used to describe the difficulty encountered in modifying resources and routines.

Since organizational knowledge is embedded in the firm's resources and routines, it will also be very hard to imitate. An imitating firm will likely be unable to observe and understand resources, their complementary relationships, the routines they are involved in, and then replicate them. Moreover, since resources and routines emerge out of adaptation to a given context, the imitating firm should not simply replicate what it eventually observes, but also adapt it to its own specific situation. Authors often refer to *stickiness* of organizational knowledge when expressing the difficulty of translating, transferring, and imitating it (Von Hippel 1994).

[6]By claiming that routines emerge mostly out of a continuous process of trial and error, this implies that they are not designed "top down" by management. As shown by Argote (1999), Argote et al. (2003), organizations develop knowledge thanks to a process of knowledge creation, retention and transfer.

[7]The difference between optimizing and satisficing economic behavior is a cornerstone of Herbert Simon's theory of bounded rationality* (1991).

## 2.3 Competitive Advantage Explained

The theory of the firm described in the previous section is not only quite fascinating, but also provides considerable explanatory power for interpreting a number of phenomena that characterize corporate life, as we usually see it.

First of all, firms are not designed "from the top down" but—rather—tend to *self-evolve*, mostly in reply to stimuli coming from the environment (in fact, this is often termed the "*evolutionary* theory of the firm"). This is not to understate the role of management, but to frame it in realistic terms. Managers are not lofty strategists and decision-makers who live somewhat separately from their firms. Instead, they are actors who are heavily involved in the organization, trying to understand the way it works and the landscape it lives in. Their key role is to progressively modify the resources set and the routines that make up their firm, in order to make it more competitive in a changing environment. Since they too are part of the organization, their work is carried out by following managerial routines that influence underlying operational routines, and they too can suffer from organizational inertia, whenever the competitive environment changes in a substantial way.

Secondly, since firms evolve, they will be *path-dependent* (Kogut and Zander 1992). Path dependency* means that what a firm is today (in terms of resources and routines) is a function of its past history, and that the state in which it will be tomorrow will be a function of what it is today and of the specific challenges it is encountering. As a consequence of path dependency and organizational inertia, firms are usually unable to make big jumps, but will tend to move in small steps, eventually running into trouble if the conditions would instead call for radical change.

A third and very important consequence is that, since firms progressively evolve in a path-dependent way, they will all be different from one another. This seems to be a fairly obvious observation but, as mentioned earlier, leads us significantly far away from the view of neoclassical economics. One particularly interesting difference between firms is related to profitability. Some firms, thanks to their differences in resources and routines, will be able to enjoy higher profitability than their peers in the same industry, thus achieving what is called *competitive advantage**. The evolutionary theory of the firm therefore suggests that the competitive advantage of a firm is not only due to managers having superior decision-making ability, but will mostly come from its different history.[8]

[8]As an example, one can think of the competitive advantage gained by Dell Computers in the '90s, by running a business model based on direct sales and Assemble-To-Order operations, which was significantly different from the prevailing model, based on Make-To-Stock operations and a complex distribution chain. Dell Computers developed this successful business model because its founder, Michael Dell, started this way in 1984, by selling computers to his friends from his college dorm room, and understood that this model could be scaled. There were countless garage-based computer assemblers like Michael Dell in the world, but he was probably unique in understanding the potential value of this model, and having the ambition and the determination to realize his vision.

Competitive advantage can also depend on luck within an uncertain environment (Barney 1991). This apparently dull statement can have a rigorous explanation. To enjoy superior profits, a firm must be able to extract economic value from resources, above the cost of the resources themselves (economists would call this an *economic rent*). If it were not for the uncertainty that surrounds the actual economic potential of resources, this rent would be extracted by the owners of resources, who would simply increase prices and draw the rent for themselves. From another perspective, and building on the fact that routines emerge out of a cumulative phenomenon, Denrell (2004) has shown that cumulative phenomena can lead to significant differences among actors even when subject to a sequence of completely random choices.

Finally, the evolutionary theory of the firm explains the *sustainability* of competitive advantage over time. As already discussed, sustainability occurs because would-be imitators will not be able to observe the tacit and sticky knowledge, the set of resources together with their complementarities, and the routines that determine competitive advantage. Moreover, because of significant causal ambiguity, they might not be able to fully understand how all this leads to competitive advantage. Finally, and even if they had successfully overcome the previous obstacles, it would be unlikely for them to successfully replicate them. As discussed above, this is due to contextual dependency, which would require adaptation of resources and routines and not simple replication, not counting the fact that similar resources might not be readily available, and that routines might require time to be developed.[9]

Curiously enough, these problems found in imitation will also be encountered by a firm that discovers some form of best practice in one of its units, and attempts to replicate it throughout its organization. Managers will therefore have to decide on the trade-off between the cost of understanding and codifying knowledge, to allow its transfer to other business units, and the opportunity cost of not doing so. At the same time, they will have to deal with the so-called *replication paradox* (Kogut and Zander 1992). Codification will make knowledge easier to transfer within the organization, thus potentially increasing competitive advantage, but will at the same time make it more accessible to imitators, thus endangering its sustainability.

(Footnote 8 continued)

Another example is the competitive advantage enjoyed by Toyota Motors Company, based on the so-called Toyota Production System set of techniques. TPS has been progressively developed within Toyota, first by Kiichiro Toyota and then by Taiichi Ohno, as a way to improve manufacturing operations under the peculiar circumstances of Japanese culture and economic environment.

[9]It is noteworthy that established competitors to Dell, such as HP, did not try to replicate its business model, but competed against Dell by improving their own traditional model. Similarly, Toyota never kept its business practices secret, but publicized them, possibly betting that this would not have allowed imitators to reach the same level of performance, but would have made it easier to find adequate suppliers.

## 2.4 Organizational Learning

If one follows the evolutionary theory of the firm, organizational learning consists in changing the firm's knowledge base and, in turn, this implies modifying its stock of resources and the routines that link them. Not all firms will exhibit the same ability to modify their resources and competencies. Therefore, it is possible to suggest (Knott 2008) that there can be something like an organizational Intelligence Quotient (IQ) for firms, intended as a measure of the organization's ability to learn, as opposed to its inertness.

Organizations are also characterized by their *absorptive capacity* (Cohen and Levinthal 1990), which is the ability of the firm to put external knowledge to effective use. In turn, absorptive capacity depends on the existence of *gatekeepers*, who are employees who are particularly apt in accessing knowledge that exists outside the firm and in interpreting it in a way that is of practical use. This allows the transfer of this knowledge to relevant employees, and its integration within routines. Moreover, absorptive capacity depends on the stock of related knowledge. Just as it happens for individuals, organizations do not learn in jumps, since the acquisition of new knowledge does not consist in the simple addition of new information but—rather—in the creation of new connections between previously acquired elements. Therefore, the ability of an organization of acquiring new knowledge will be proportional to the extent with which this new knowledge is related to the knowledge it already possesses.

In general, it is possible to define four generic modes of organizational learning (Huber 1991). In Chap. 8, the discussion will be expanded to identify specific strategies and activities, given the managerial relevance of decisions pertaining to what and how to learn.

**Innate learning** is what gives rise to the initial knowledge base in a company, at the time of its foundation. Since there are no routines yet, this knowledge base will come from the contribution of its founders, tied together by a common vision of the world and a common objective, such as the one that can be found in a business plan.

**Experiential learning** is the typical process by which firms modify their routines thanks to "learning by doing" and "learning by failing", by following a trial and error mechanism, and/or performing in-house Research and Development (R&D) activities. An important distinction can be made between *exploitation learning* and *exploration learning* (March 1990). The former occurs when a company operates normally and runs its routines as usual (i.e., it exploits its existing knowledge) and, in doing so, discovers some form of improvement, thus generating new knowledge. Instead, exploration learning happens when a company attempts something that is purposely new (e.g., it ventures in a new market or explores new technology) and, in doing so, it builds new experiences and routines. Path dependency will of course constrain the ability of the firm to achieve experiential learning. Both exploitation and exploration learning can occur unconsciously, or can be deliberately pursued by the firm.

**Vicarious learning** happens when the firm attempts to tap into an external source of knowledge, such as advice provided by a consultant, or a book. The first issue at stake in this process is the identification of the knowledge required, which can happen through *scanning* (i.e., searching across a wide spectrum of possible sources) or *focused search* (i.e., searching in a specific direction). Once this knowledge has been identified and acquired by the firm (e.g., a consultant has been hired, or a book has been bought), it has to be diffused in the organization and put to use in its routines. It is quite apparent that vicarious learning will be heavily dependent on the organization's absorptive capacity.

There is a subtle relationship between experiential and vicarious learning. Since absorptive capacity is related to previously held knowledge, companies who wish to be effective in vicarious learning should also practice experiential learning. Translated in practical terms, this means that firms who want to tap into external knowledge sources must nonetheless perform some amount of internal R&D, to achieve and maintain a sufficient alignment with the state of the art.

**Learning by grafting** occurs when the company gains new knowledge by hiring an individual, or by acquiring another organization, and integrating them within its organization. This approach to learning is apparently faster than the previous ones, since knowledge does not need to be developed. However, integration of the acquired resources is by no means costless and trivial, since it requires to alter existing routines and/or to create new ones.

Though valuable, organizational knowledge can be a double-edged sword for firms (Zhou and Wu 2010). As depicted in Fig. 2.2, the stronger an organization's knowledge, the larger the benefits it will achieve by pursuing "exploitation" activities that build on that same knowledge. If one considers activities that require "exploration" of adjacent knowledge, the benefits will at first grow with the strength of the firm's knowledge, due to increasing absorptive capacity. Beyond a given point, benefits accruing from exploration projects will however start decreasing, because of organizational inertia created by the strong knowledge base. Beyond this point, the firm will find it easier and more efficient to stay on the same path and follow exploitation-based activities only. This phenomenon is called a *competency trap*, since it leads a company to become locked-in, or imprisoned, to its own strengths.

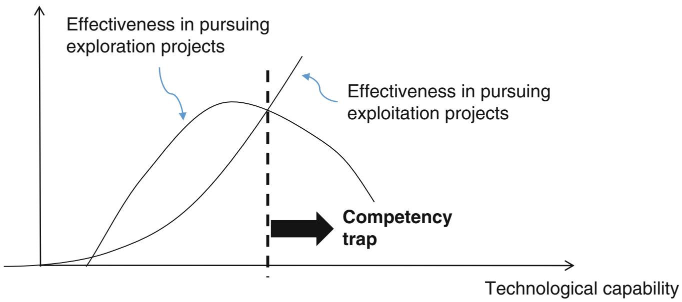


**Fig. 2.2** The phenomenon of competency trap

The consequences of a competency trap can be quite dramatic, if the environment in which the firm operates changes significantly, and the firm is unable to adapt to it.

As discussed by Lee and Van den Steen (2010), the risk of falling into a competency trap becomes even greater for firms that actively involved in knowledge management practices aimed at identifying best practices and codifying them. In fact, the firm might end up codifying and formalizing practices that are only moderately successful, or might even be damaging, should the environment change.

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# Chapter 3
# The Many Types of Innovation

After having covered the main theoretical foundations, we can now fully delve into the topic of innovation. The first main issue, which will be covered in this chapter, is to understand the different types of technological innovation, their determinants and their implications for individual firms and industries.

## 3.1 The Determinants of Innovation

When dealing with technological innovation, the first significant question that has to be answered is related to its causes, or *determinants*. Over the years, two possible and contrasting determinants have been identified. According to advocates of *technology push*, innovation occurs when a technological development is generated independently from a specific market need and is eventually deployed in a given industry, thus matching a latent demand. Such a technological development can be generated internally to the innovating firms, or can occur elsewhere, in which case the innovating firms will realize the potential behind the technology and incorporate it in products and services.[1] Conversely, *demand pull* posits that firms observe the demand for improved products that comes from the market and from society at large, and explicitly direct the development of technology to respond to these needs.[2] The debate between these two determinants has been quite active, until scholars have realized that technological innovation can be due to either of the two, depending on the stage and type of innovation.

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[1]For instance, think of the development of laser technology. This technology had originally been developed without a clear commercial application in mind. Over the years, it found multiple applications that have revolutionized entire industries, from CD players to metal cutting and from telecommunications to barcode scanners.

[2]Today's cars have a significantly lower environmental impact than their predecessors, and most of the innovations introduced have been directly developed by the automotive industry in response to market and societal needs. Examples of innovations in the automotive industry that have stemmed from technology developed independently from the needs of this sector are, conversely, very few.



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_3

This conclusion comes from the observation that technology does not follow a linear process, but is subject to distinct and alternating phases of *evolutionary* and *revolutionary* progress (Tushman and O'Reilly 1997; Iansiti 2000). If we pick an industry and identify a relevant performance indicator for its products, the evolution of this indicator will not proceed in a straight line, but follow a sequence of *s-curves*. As an example, we can study the evolution of passenger airplanes, and collect data on cruising speed, range, capacity and fuel efficiency for a selection of models that have been particularly important in civil aviation history (Table 3.1).

Table 3.1 shows that, throughout the twentieth century, the industry has progressively evolved toward faster and larger airplanes, progressively changing the underlying technology used for airframes (from wood to metal and then to composites) and for engines (from internal combustion engines and propellers, to jet engines and then to turbofans). We can make a qualitative representation of this evolution with *s-curves*, with performance indicators on the Y axis and time on the X axis, as in Fig. 3.1.

S-curves show that, when a technology emerges, performance is usually quite low, until a sufficient degree of maturity is reached. At this point, performance starts growing at a significant speed, until it eventually reaches a *technological limit*, i.e., a performance level that cannot be overcome due to limitations that are intrinsic to the technology.[3]

Once the limit has been reached, firms that want to improve their products will have to embrace new technical solutions (for example, moving from piston and propeller powerplants to jet engines). In doing so, firms must choose among a number of new candidate technologies available, and decide when to do so. The former aspect is critical, since only one technology will generally prove to be suitable and emerge (ref. the concept of *paradigm* in the next section and of *dominant design* in the next chapter). Figure 3.1 shows a number of choices that have not been successful, because the technology was not good enough, or because it did not match customer needs (for instance, flying boats could only connect cities that were located close to a suitable stretch of water). The timing aspect is also important, since a premature investment may lead to unattractive returns from a financial point of view or—even worse—to erroneous choices in technology. Conversely, a late investment may forfeit gaining experience with the new technology and an early access to the market. In some cases, early adoption of the new technology might prove to be advantageous and lead to what is commonly termed *first mover advantage* (more on this concept will be covered in the next chapter too).

In general, *evolutionary progress* occurs when moving along a given s-curve, while an industry will experience *revolutionary progress* when transitioning from an old s-curve to a new one. Demand pull will be the prevailing determinant of

[3]For instance, an aircraft powered by an internal combustion engine and a propeller cannot practically go faster than 600 km/h, because of cavitation and because of the speed reached by propeller blades. Moreover, the piston engine cannot work if air pressure is too low, and will therefore operate only at altitudes below 7500 m.

**Table 3.1** Planes and the underlying technologies throughout the twentieth century

| Airliner | Year | Airframe | Engines | Cruise speed (km/h) | Range (km) | Max passengers | Fuel efficiency (km seat/l) |
|---|---|---|---|---|---|---|---|
| Flyer | 1903 | Wood + fabric | 1 piston + propeller | 48 | – | 1 | – |
| Farman Goliath | 1919 | Wood + fabric | 2 piston + propeller | 120 | 400 | 14 | 13.4 |
| FIAT C.R. 32 | 1933 | Metal | 1 piston + propeller | 315 | 750 | 1 | 2.2 |
| Douglas DC-3 | 1935 | Metal | 2 piston + propeller | 333 | 2400 | 32 | 8.4 |
| Boeing 314-flying boat | 1938 | Metal | 4 piston + propeller | 340 | 5900 | 74 | 23.5 |
| Vickers Viscount 700 | 1948 | Metal | 4 turboprop | 496 | 2220 | 48 | 15.3 |
| De Havilland Comet | 1949 | Metal | 4 turbojet | 740 | 2400 | 44 | 3.56 |
| Boeing 747-100, 200 | 1970 | Metal | 4 turbojet | 893 | 12,690 | 550 | 26.9 |
| Concorde | 1976 | Metal | 4 turbojet | 2158 | 7222 | 120 | 6.4 |
| Helios | 2001 | Composites | Solar powered | 300 | 7200 | remote control | – |
| Boeing 787 | 2011 | Composites | 2 turbofan | 913 | 15,400 | 440 | 36.6 |

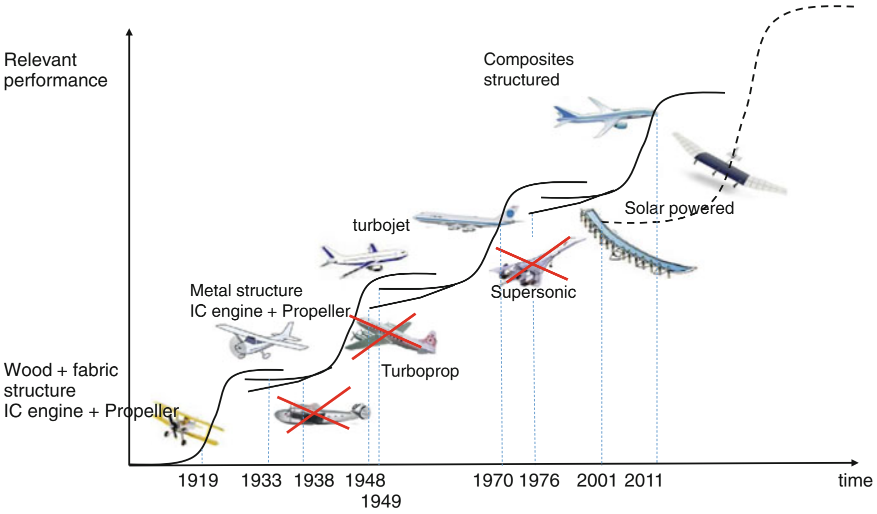


**Fig. 3.1** A qualitative depiction of the progress of civil aviation history using s-curves

innovation that accompanies evolutionary progress, during which a given technology is improved and fine-tuned according to customer needs. Conversely, technology push will mainly occur in the revolutionary phases, when firms are forced to "look around" for new solutions that may overcome the technological limit that characterizes the current technology.

S-curves are a fundamental instrument in the toolbox of those who deal with technological innovation as scholars or as practitioners. However, they should be treated with some caution. First of all, one should choose a performance indicator that represents technological progress, but should most of all be representative of user needs, which are difficult to identify and might also change over time.[4] Secondly, using time as the independent variable can be misleading, since technology does not improve simply because time goes by, but because of the investment and the effort that companies spend on it. Therefore, s-curves should not really be drawn as a function of time, but of cumulated industry-wide R&D expenditure. Using this variable implies that technological improvements occur because firms imitate each other and therefore build on each other's investment. Data on R&D expenditure is not always easy to find, and cumulated sales at industry level are often used as a proxy. The rationale is that R&D expenditure usually is a fairly constant and industry-specific percentage of sales, and the two are therefore proportional. Using time as an independent variable is risky, since s-curves might flatten not because a genuine technological limit has been reached, but simply because companies in the industry have reduced their R&D spending. In this case, one might be drawn into thinking that the old technology has reached its apex, make a premature investment in the new technology, only to discover that, by "adding a bit of R&D" the old technology gains a strong lead again.

## 3.2 Technological Paradigms

Each of the s-curves described in the previous section does not simply represent a technology, but a broader concept that can be termed *technological paradigm*.[5] As shown in Fig. 3.2, a technological paradigm is a mixture of supply-side and demand-side elements that blend together in a coherent whole and give birth to a technological *trajectory* (i.e., the s-curve) that is at the same time viable for companies, and appreciated by the market.

From the side of supply, a paradigm is made up of theories, knowledge, tools, and methods that allow transforming a given technology into actual products and services, around which a sustainable business model can be established. In order for a new paradigm to emerge, the industry must therefore be capable of mastering the new technology, and must also be able and willing to forget the concepts and the

[4]The previous case of civil aviation provides a clear example. Having taken for granted that speed was the main performance to be pursued, led to the commercially disastrous development of supersonic passenger planes such as the Concorde*. Instead, fuel economy and passenger comfort have progressively become the main performance being sought by airlines. This explains why composite materials, allowing the production of lighter and comfortable airplanes, are currently emerging as the characterizing technology in passenger aircraft.

[5]Giovanni Dosi introduced this term in 1982 by borrowing it from Thomas Kuhn's concept of scientific paradigm*.

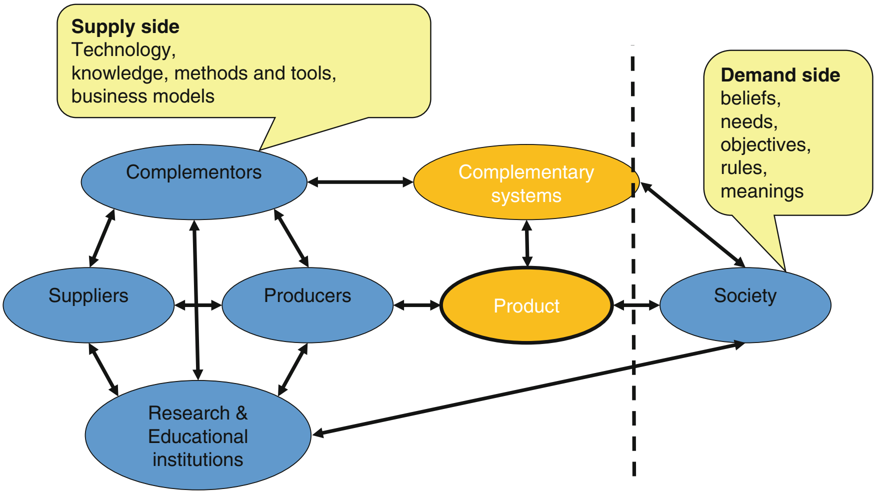


**Fig. 3.2** The constituent elements of a technological paradigm

know-how that was attached to the previous one. The emergence of a paradigm requires the coherent coming together of a number of actors. The main role is of course covered by producers and their suppliers. A major part is also played by *complementors*, which provide products and systems that are complementary to the main product. Finally, research centers and universities are essential for providing the underlying knowledge and an appropriately trained workforce.

From the side of demand, a paradigm is defined by beliefs, needs, objectives, rules, and *meanings*[6] that customers attach to the product. If these are met by the technology, customers will choose it, and the paradigm will emerge. Instead, if the features of the product conflict with what customers believe or need, the paradigm will not emerge or, at the least, will be delayed.

The concept of paradigm, and the interplay between the bundle of supply-side and demand-side elements that define it, can help explain why a specific technology

[6]The concept of meaning is central to many products. Especially when dealing with consumer markets and products associated to industries such as food, fashion, and design, evaluation is not carried out on the basis of technical performance alone, but by looking at subtle and deeply personal aspects (Verganti 2009). This so-called *co-constructivist* perspective on innovation states that products stay alive as long as there is a social network of actors that see value and meaning in producing and purchasing them. For instance, one can think of the technological innovation behind high-end mechanical watches, which is generally targeted toward achieving greater "complications". The relevant customer segment assigns very high economic value to these complications because of the very peculiar cultural meaning attributed to reaching complex results with traditional mechanical technology. It is clear that this meaning goes well beyond the main function of a watch (i.e., telling time), which could very well be covered by an inexpensive quartz movement.

may emerge or fail during a technological revolution.[7] Of course, it is always easier to use theory for retrospectively interpreting history, than using it to forecast what will happen in the future.

In some cases, a new technology can overcome an existing one, without the latter actually having to reach its limit, but simply because the former provides higher performance and/or a combination of features that the market considers to be superior. In this case, one can speak about *discontinuous technology* (Schilling 2009). Quite often, discontinuous technology does not simply lead to advancing a specific technical performance, but to a radical change in the way with which the market understands, conceives, and ultimately uses the product.[8] In such sense, discontinuous technology can lead to a new technological paradigm.

From a managerial perspective, the concepts outlined above suggest that firms must constantly be aware of which phase of technological progress they are operating in and take appropriate actions, be it the development of known technology, the scouting for new technologies, or trying to make a newly chosen technology prevail over competing ones being backed by competitors. More specifically, these concepts suggest that the marketing and R&D functions have highly complementary roles in the innovation process (Cooper and Kleinschmidt 1990; Calantone et al. 1993). Marketing and R&D must also behave differently when operating in evolutionary or revolutionary phases. During evolutionary times, marketing has the role of achieving a deep understanding of customer needs and direct R&D efforts accordingly. In revolutionary phases, R&D must identify promising technology, while marketing will at first provide selection criteria. Then, marketing will also have the responsibility of turning back to customers and convincing them that the features of the chosen technology meet their needs, both explicit and latent.[9]

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[7]For instance, the cloud computing paradigm is progressively overcoming the client-server paradigm that dominated computer systems since the ’80s. The reason behind this success is tied to the convergence of supply-side and demand-side factors. Among the former, the economies of scale that can be achieved by centralizing data processing and storage, and the widespread availability of cheap and reliable bandwidth for connecting servers with clients. Concerning the latter, users have valued the possibility of accessing online services through multiple devices, both fixed and mobile. Moreover, users have been confident that an Internet connection will always be with them, while they have been quite unconcerned of privacy issues associated to the personal data they entrust to service providers.

Similarly, the technology that will power the car of the future will depend on technological progress, but will also depend on users’ attitudes. Specifically, one can wonder whether users will really be “range anxious”, as many current surveys suggest, or whether they will realize that driving electric cars that have a limited range perfectly suits most driving patterns.

[8]For example, the shift from film-based photography to digital has not simply been a matter of image quality and cost, but has most of all led to a deep change in the way with which photography is used and enjoyed by consumers.

[9]When dealing with revolutionary change, using input from market research can be highly misleading. Henry Ford is credited to having said that, if he had asked potential customers what they wanted, the answer would have been a faster horse, and not an affordable motor car.

## 3.3 A Taxonomy for Technological Innovation

The previous section has allowed us to identify evolutionary and revolutionary innovations, by looking at their relationship with the concept of technological paradigms. Innovations can also be classified according to a number of other perspectives, which have interesting managerial implications. As the title suggests, we now are focusing on technological innovation only, while other types of innovation will be introduced in the following chapters.

- Innovations can be defined as *incremental* or *radical* (Dutton and Thomas 1984), by looking at the technical features of the product (i.e. its functions and performance) and—more specifically—at whether the innovation significantly changes the technical trade-offs that define it. In general, both producers and customers look at products as "bundles" of functions and performance indicators, in which one can readily identify trade-offs. An incremental innovation will consist in an improved product that does not significantly alter these trade-offs. Conversely, a radical innovation will lead to products that introduce completely new functions, or a set of performance values that clearly set them apart from their predecessors by breaking established trade-offs.[10]
- Innovations can be *competence enhancing* or *competence destroying* (Anderson and Tushman 1990), by considering the knowledge that is required to develop new products. When dealing with a competence enhancing innovation, a firm leverages its existing stock of knowledge and—in pursuing the innovation—adds to it, thanks to experiential learning (as discussed in Chap. 2). Conversely, a competence destroying innovation will require the firm to set its existing knowledge aside, and gain new and possibly unrelated competencies.
- Innovations can also be *core* or *peripheral*, depending on whether they affect a core functionality of the product, or an ancillary one.
- Finally, innovations can be *sustaining* or *disruptive* (Christensen 1997) if one looks at their impact on the industry. A sustaining innovation will not lead to significant change in competitors' positions and market shares, while a disruptive one will lead to major changes. With disruption, market leaders may fall behind, or even exit the industry, while leadership may be achieved by firms that previously had a minor role, by new entrants, or even by startups. This topic is of extreme managerial interest, and will be the subject of the following section.

When studying a given innovation, its classification will not only depend on the criterion being used, but also on the position in the value chain of the firms being

[10]For instance, a typical trade-off in a motor car can be found between performance (e.g., speed and acceleration) and fuel efficiency. An incremental innovation would improve the existing technology without substantially altering this trade-off. A radical innovation would instead be such as to enable the development of a high-performance sports car that has the same fuel efficiency of a city car.

considered (Afuah and Bahram 1995).[11] Therefore, it is possible to state that the type of innovation is to some extent "subjective", and that firms must consequently keep value chain structure in mind when thinking about their innovation strategy.

Finally, one can classify innovation in a slightly more complex way, by observing the two axis of underlying technology on the one side, and of *product architecture* on the other (Henderson and Clark 1990). To explain this concept, it is at first necessary to define product architecture. For the time being (a fuller definition will be provided in Chap. 16), it is possible to state that product architecture is defined by the main components that make up the product and their mutual relationships (see the *block diagram* in Fig. 3.3, top left). These relationships may be due to functional interactions, physical proximity, or even unintended influences. The design of each component will generally be assigned to a specific organizational entity (be it an individual or a team), and these entities will have to communicate with each other in a way that replicates the pattern of intercomponent relationships (Fig. 3.3, top right). Therefore, product architecture and the organization will share a similar structure. As we have discussed in Chap. 2, most of these communication flows will not be explicit and formalized, but will occur in the form of organizational routines that emerge out of experience and of trial and error.

Now, should the firm change product architecture (Fig. 3.3, bottom left), it will not be straightforward for the organization to adapt to this change by identifying new routines and communication flows, and discarding obsolete ones (Fig. 3.3, bottom right). Therefore, innovations leading to change in product architecture will be difficult to manage.

Based on the previous discussion, it is possible to identify four types of innovations (Fig. 3.4).

- In *incremental innovation*, neither the underlying technology, nor product architecture will change (e.g., a product development team that is working on the geometry of an automotive braking system to improve heat dissipation). This kind of innovation can be costly to achieve—in terms of effort—but is not difficult to manage, since it completely replicates the experience gained with previous products.
- In *modular innovation,* underlying technology does change in one or more functional elements, but product architecture does not (e.g., an automotive company that switches from a traditional instrument panel to an LCD screen

[11]For example, suppose that a battery maker invents a completely new battery for portable electronics devices, with energy density that is orders of magnitude greater than in existing ones. The innovation will be radical for both battery makers and device makers (for the battery maker, it significantly changes the trade-off between energy storage and size while, for the device maker, it alters the trade-off between features, size, computing power, and battery time). The innovation will probably be competence destroying and core for battery makers, but not for device makers. Similarly, it will probably be disruptive for battery makers but sustaining for device makers, unless it is supplied under some kind of exclusivity clause to a single device maker.

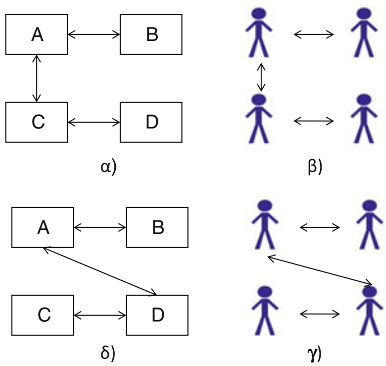


**Fig. 3.3** The organization mirrors product architecture

**Fig. 3.4** The taxonomy by Henderson and Clark

| **Relationships between components** / **Reference technologies** | **Do not change** | **Change** |
|---|---|---|
| **Change** | Modular innovation (e.g. high capacity batteries in cell phones) | Radical innovation (e.g. PCs vs typewriters) |
| **Do not change** | Incremental innovation (e.g. faster spinning hard drives) | Architectural innovation (e.g. rear-wheel vs front-wheel drive cars) |

with virtual indicators). In this case, the innovation in the affected modules may be significant and difficult to pursue, since it requires changing the competencies used. However, problems will be limited to the affected modules, and the development of the complete product will therefore be relatively easy to manage.

- In *architectural innovation*, underlying technology does not change, but inter-component relationships do (e.g., a carmaker specializing in luxury saloons that starts developing a small city car). Architectural innovation is generally hard to manage, since the organizational routines that allow the development of a consistent product will not be immediately available, but will take some time (and probably some costly mistakes too) to develop. This will be especially true if the new pattern of relationships between components is known *ex-ante*. In some cases, architectural innovation may take companies "by surprise" because seemingly minor innovations unexpectedly change intercomponent relationships.
- In *radical innovation,* both underlying technology and product architecture change (e.g., a carmaker switching from a traditional vehicle to an electric car). This kind of innovation is of course the most difficult to pursue, even though it is not very common, and firms will also be well aware of the problems they will

face when tackling it. When dealing with radical innovation, firms are often so wary of architectural change that they will try treating it as modular, by changing product subsystems one by one, but trying to steer away from altering their mutual relationships.[12] This hesitation in embracing radical innovation opens up interesting opportunities for firms that—instead of making piecemeal changes to the existing architecture—accept the challenge of jointly changing technology and product architecture.

## 3.4 The Puzzling Nature of Disruptive Innovation

When studying innovation, one can wonder why radical innovation can ever be disruptive. In fact, it is quite puzzling to observe *incumbent** companies (i.e., companies who are already operating in the industry), which are generally large, established, and well-run, act somewhat helplessly when facing the challenge arising from *entrants* (either companies that were operating in other industries, or *startups*). This is quite striking, given that the latter are often smaller in size, must overcome *barriers to entry** and lack experience in the industry.[13] Understanding the mechanisms behind disruptive innovation is of course important both for incumbents, who want to stave off competition, and for entrants, who instead want to gain a foothold in the market. Literature suggests three main reasons for disruptive innovation: inability to join an emerging paradigm, neglect of an emerging market, differences in the goals of incumbents and entrants.

### *3.4.1 Incumbents Can Be Unable to Join the Emerging Paradigm*

The first reason behind disruptive innovation is the most dramatic, though probably not the most common, and occurs when two conditions are met. The first condition is that the old technology does not keep pace with growing or new user needs, while

[12]For instance, early cars were built in the guise of horseless carriages (and were even named as such). Similarly, if one looks at the first electric cars being marketed in the 2010s, their architecture mimics very closely the one of traditional vehicles, with a single engine in the front, a complete transmission with gearbox and differential, and batteries located in the rear of the car. It is likely that future electric cars will have a different architecture that fully exploits the potential of the new technology, with electric wheels (i.e., motors directly coupled to the wheels) and batteries spread in the underbody of the car. In a different field, early digital cameras were developed by taking a traditional camera body and adding a "digital back" with a sensor located on the film plane.

[13]For instance, one can think of the emergence of Microsoft when personal computers and client–server architectures entered the scene and—when IT shifted to the cloud computing paradigm—the fast growth of a company like Google.

the new technology does, and this creates the opportunity for paradigm change. The second condition is that the new technology requires competencies and assets that are very distant from the ones relevant to the old paradigm. Incumbents, who are unable to deal with a competency-destroying innovation, therefore turn out to be unsuccessful in pursuing paradigm change.[14]

The inability to switch paradigm depends on both objective and subjective factors. The main objective factor is the distance in technology and associated competencies between the two paradigms. Subjective factors are instead due to incumbents' responses to radical innovation that can suffer from inertia both in understanding the new situation (*cognitive inertia*) and in reacting effectively to it (*action inertia*). While action inertia is essentially due to path dependency in the routines that define a firm, cognitive inertia derives form managers' tendency to follow ways of thinking that were applicable in past paradigms, but are no longer valid in the new one. This phenomenon can be attributed to a number of *cognitive traps*:

- The first trap incumbents may fall in is to look at the sources of competitive advantage and to the strategies that have granted them success in the past. Companies that have successfully survived until the end of a paradigm usually have a strong understanding and confidence in the weapons that made them win many battles, and will tend to heavily rely on them. However, the value of these assets and strategies within the new paradigm may be very low indeed.
- A second trap is related to incumbents' unwillingness to abandon an old technology because of previous investments that represent *sunk costs*.[15] The marginal cost of developing new products based on the old technology can effectively be much lower than switching to the new one, which would instead require new investments. However, assets connected to the old technology usually represent a sunk cost in the short-term only since, in the medium to long-term, they will have to be replaced and/or maintained. Therefore, the cost of remaining with the old paradigm tends to be underestimated.
- A third trap is related to observing the *status quo* and not thinking ahead, which can lead incumbents to reply to paradigmatic change when it's too late. If one focuses on the status quo in the early days of paradigm shift, the new technology

[14]A well-known example is the case of refrigerators, who progressively led to the demise of a very successful ice trade* industry in the nineteenth Century. Physical assets and competencies that made an ice production and trading company successful were clearly useless for producing refrigerators. The main incumbents tried staving off competition by lowering the price of harvested ice (a simple strategy that often allows to "buy time"), but this simply accelerated their fall. A few other incumbents left the industry and redeployed part of their assets and competencies to industries where they could be of value (i.e., fresh produce logistics).

[15]A sunk cost is an investment that has already been made and that is not recoverable, because the material or immaterial asset that has been bought is highly specific to a given technology or use, and can therefore neither be resold, nor put to an alternative use.

will generally exhibit low performance and will not appear to be particularly attractive. However, while the old technology has probably reached its limit, the new technology still has plenty of upside, and its sudden growth is likely to catch incumbents by surprise.

### 3.4.2 *Incumbents Tend to Neglect Emerging Markets*

A second and very common reason for disruptive innovation is due to incumbents' focus on their reference markets, which is sometimes called the "Christensen effect" (Christensen 1997). Incumbents are strongly influenced by what they perceive as the needs of their current customers and take care that the performance they offer exceeds what is required by the market (and this, of course, is good business practice).

When a new technology emerges, it is likely that its initial performance will be inferior to the one achieved by the established technology and to what current customers expect. Incumbents are well aware that performance of the new technology will grow at a significant rate and eventually make it threatening to the old one, but not immediately. Therefore, they tend to keep an eye on it, and they sometimes even make R&D investments to pioneer it. However, they also tend to delay its introduction in new products.

As it often plays out, the inferior performance of the new technology may be perfectly satisfactory for a completely new market that the incumbents overlooked, which may have different needs than the existing one, and that favors the radical innovation. Sometimes this new market may be looking for a low-performance and low-cost solution. At other times, the new market may appreciate a *different* performance mix. This new and "untapped" market may sometimes be a small niche that nonetheless allows entrants to establish a beachhead, reinvest margins from sales in R&D, accelerate technological development, and bring the day at which the new technology will become competitive forward. In other cases, the new market may be even larger than the existing one, and of course this leads to a very quick disruption of the industry.[16] (Fig. 3.5).

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[16]There are many examples to this explanation of disruptive innovation. When personal computers appeared in the '80s, their performance was significantly inferior to the mainframe computers in use by firms, but was more than acceptable for home or small-office use, while their price was considered to be affordable.

In the case of digital photography, Kodak was a pioneer in digital imaging technology. However, due to the excellent resolution and low cost of film, it mostly considered digital technology as a complementary tool aimed at professionals. It did not foresee that somewhat pricey and low resolution (e.g., 3 MPixel) digital cameras would diffuse rapidly in the consumer market, since the use of digital photography was completely different from traditional photography, and provided consumers with a different bundle of benefits.

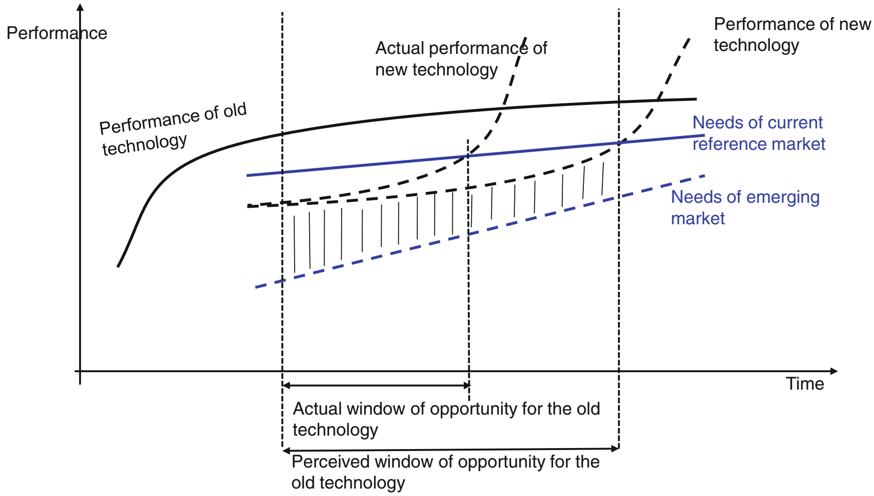


**Fig. 3.5** The Christensen effect

This explanation of disruptive innovation leaves some open questions regarding what seems to be a very myopic behavior by incumbents. Again, subjective factors have a strong role in explaining the rationality of this behavior:

- Given that "customers pay our bills", companies will naturally tend to give great importance to what they think customers need, and overweight market risks with respect to technological risks. Therefore, incumbents often pioneer radically new technology but then hesitate in bringing it to the market, "because that's not yet what our customers want". As a managerial implication, incumbent firms should consider both current and potential customers that might be attracted by the radical innovation. This requires adopting a wider stance when dealing with market research, using it to envision new markets and not only to exploit existing ones.
- The decision-making process in incumbent companies also can have a strong influence. Incumbent companies usually enjoy high profitability and this creates expectations in the minds of shareholders. Even though this profitability is bound to be abruptly ended by disruptive innovation, the status quo makes it difficult for top management to justify what will be perceived as the *cannibalization* of a successful business model and the pursuit of a risky endeavor in an uncharted territory. In other cases, managers and shareholders might in principle be inclined toward this choice, but the issue is simply never placed on their agenda. This generally happens when proposals for radical innovation emerge bottom up instead of being championed top down. If a proposal for a radical innovation comes from the lower ranks of management (e.g., a project leader in the R&D unit), it is likely that it will be culled by the managers to which it is immediately presented (e.g., a middle manager in the R&D unit).

These may in fact appreciate the idea, but realize that they are not in a position to make strategic choices of this kind, which would require deep changes to parts of the business model they do not control, and hesitate in bringing it to the board of directors, which is the only entity that could make decisions of this kind. Therefore, top management should always have a strong awareness of potentially radical innovations, and be ready to challenge both internal and external stakeholders who may exert pressure in keeping the status quo. Moreover, top management should create communication channels exposing them to innovative ideas, thus avoiding that these same ideas may be filtered away by intermediate layers of management.

### 3.4.3 Incumbents and Entrants Have Different Goals

The third and final explanation for disruptive innovation is that incumbents and entrants are naturally inclined to pursuing dissimilar objective functions, and this naturally leads to different choices with respect to timing of entry. Therefore, firms will act as either:

- *First movers*, i.e. the firms that are the first to offer products and services associated to the radical innovation.
- *Early followers* (or fast followers), which are the firms who enter the market during the first phases of diffusion, but after the first movers have started operating.
- *Late entrants*, who enter the market when the product has already experienced widespread diffusion.

As shown by Swinney et al. (2011), timing of entry can be associated to incumbents' and new entrants' different goals. Incumbents are usually concerned with profitability of the business as a whole, and therefore tend to maximize the expected Net Present Value of an aggregate portfolio of projects, E[NPV]. Conversely, entrants are concerned with survival, and will therefore strive to minimize the probability of failure over a limited portfolio of projects, P[NPV > 0].

The timing at which radical innovation is pursued will depend on uncertainty of demand and on the trend with which the required investment is expected to evolve over time. The optimal choices by entrants and incumbents are fairly intuitive and, without delving in the details of the model, they can be summarized in Fig. 3.6.

If actors expect investment cost $\Delta C$ to be decreasing (e.g., because of exogenous technological developments) both will decide to wait. If they expect costs to remain constant or increase, their response will depend on demand uncertainty $\sigma^2$. If uncertainty is low, they will both enter early. However, demand uncertainty for radical innovation will generally be high, and this will at the same time reduce

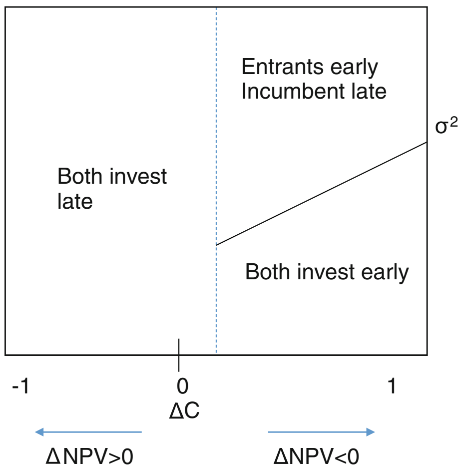


**Fig. 3.6** Incumbents and entrants purse radical innovation with different timings

expected profitability and increase chances for survival. It will therefore be rational for an entrant to act sooner than an incumbent, thus creating the opportunity for disruptive innovation.

### 3.4.4 *Incumbents' Need for Ambidexterity*

The previous discussion should have made clear that it is not easy for an incumbent to successfully deal with radical and competence-destroying innovation. There will be an obvious aversion to embrace it, since it will be perceived to be risky for the existing business. Furthermore, the radical innovation will succeed only if financed by the proceeds coming from that same technology that will be supplanted by it. It is therefore no wonder that paradigmatic change leads to involved and time-consuming decision-making processes within incumbent firms.

To tackle this challenge successfully, scholars have introduced the concept of organizational *ambidexterity* (Tushman and O'Reilly 1996, 2004; Gibson and Birkinshaw 2004).

An ambidextrous organization is able to maintain efficiency in the current business models and technology, at the same time reading itself to adapt for the future. Ambidexterity is not only a cultural attitude, but requires specific strategies and organizational actions, to make sure that both "incumbent" and "radically innovative" projects and units are able to progress under close coordination by top management. The former will have to be managed in a more formalized and standardized way, while the latter will have to be coordinated with greater freedom.

## 3.5 When Radical Innovation Does not Disrupt

The previous discussion should not lead to the popular conclusion that radical innovation always and invariably leads to disruption. On the contrary, radical innovation often does not lead to disruption at all, though this outcome is seldom discussed in both professional and academic literature. This asymmetry is probably due to the fact that it is quite difficult and certainly less attractive to study a non-event, than a visible outcome. However, both incumbents and entrants need to be well aware of the reasons because of which disruptive innovation might not materialize.

One possible reason is due to the existence of *markets for technology.* Given the fact that incumbents have clear competitive advantages, a threatened incumbent and an entrant may find a deal, with the former acquiring a license for using relevant technology from the latter, or directly acquiring the entrant company. This latter case is especially common in the case of venture-backed startups. Venture capital firms have the objective of achieving returns on the capital invested in startups within a given time frame (the so-called *exit*). This can occur either by a *trade sale**, or by listing the company on the stock exchange through an *Initial Public Offering** (IPO). From their perspective, it is often worthwhile to have a trade sale early on, rather than starting a lengthy and uncertain path, leading to competition with the incumbents and, only if successful, achieving an exit through an IPO.

In addition, radical innovations may not lead to disruption because of the two reasons that will be discussed in the following subsections: unforeseen behavior in the technology s-curve, and the so-called phenomenon of *localized technological change*.

### *3.5.1 S-Curves Can Be Misleading*

Truly disruptive innovation usually requires that the old paradigm has really reached an endpoint, and evidence from "flattening" s-curves is commonly used for this purpose. However, the use of s-curves if quite critical and can be misleading.

- To begin with (left-hand diagram (a) in Fig. 3.7), s-curves are not usually smooth, but are made up of nested s-curves that represent what are familiarly called *product generations*. Some degree of saturation will be observable throughout the s-curve, and it will not be easy to discriminate whether this saturation is soon to be overcome by a new product generation, or whether it represents a real technological limit that is inherent to the paradigm. In the former case, there might be some industry disruption when transitioning

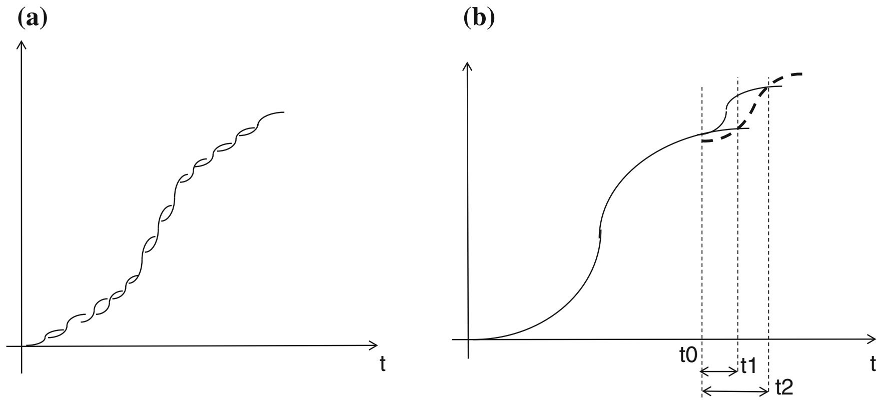


**Fig. 3.7** Nested paradigms and the sailing ship effect

between product generations, but this will be on a minor scale to what would be expected from a full transition between paradigms.[17]

- Moreover, s-curves are usually drawn by using time as an independent variable. What seems as saturation may therefore not be due to a technological limit, but simply to the unobserved slowing of R&D effort. Faced with the threat of an emerging technology, incumbents are likely to react by restarting a new investment cycle on the old technology and quickly regain a performance lead. In some cases, elements of the new technology may *spill over* and make it easier for incumbents to further improve the existing technology. As shown in the right-hand side (b) of Fig. 3.7, this reaction allows incumbents to extend their lead with respect to the emerging technology from time $t_1$ to $t_2$. In some cases, this reaction will simply "buy some time" and defer the date at which the new technology will displace the old one. In other cases, the advantage gained may be so significant as to effectively discourage entrants and stop the development of the new technology in its tracks. In some cases, incumbents' reaction may give them a lead across all market segments. In other cases, incumbents may retreat to segments where the old technology can maintain this lead for a longer time. This phenomenon is often termed the *sailing ship effect** (Geels 2005), following the significant performance increase in long-range sailing ship technology that came along in the nineteenth century, when competition from steamships started to arise.
- Finally, it has to be verified whether the radical innovation affects the entire product (in Henderson and Clark's terms, if it really is radical innovation, involving architectural change as well) or whether it is mostly localized at the

[17]In fact, one of the case studies introduced by Christensen in his theory of disruptive innovation was related to successive generations of hard disk drives, which did not represent real paradigm shifts.

level of individual components (i.e., if it is closer to modular innovation and does not require architectural change). In the former case, the innovation is likely to be disruptive and favor new entrants. In the latter case, the innovation will probably not be disruptive at all at product level, since incumbents will find it relatively easy to embrace. If any disruption might occur, it will be at the level of affected components and subsystems.

### 3.5.2 Localized Technological Change

A second reason why radical innovation might fail to lead to disruptive effects lies in the theory of *localized technological change* (Antonelli 1995). The idea behind this theory is that, when a new technology emerges, each potential customer continuously evaluates whether to switch or whether to keep on using the old technology. This evaluation will be carried out by considering relevant costs and benefits, along with *switching costs**. Now, the benefits delivered by the two technologies are not only based on their objective performance, but also on factors that are highly subjective to each user.

Specifically, utility gained by the users of the old technology will depend on the investment that has been progressively accumulated in complementary assets and on the experience gained by using it for a long time. If these assets and this experience are specific to the old technology and are therefore not usable with the new one, this will significantly reduce the subjective attractiveness of the new technology. Therefore, the performance gap that would justify switching increases and adoption is delayed. In these cases, customers are said to be *locked-in* the old technology. Similar reflections can be made by looking at the new technology, and evaluating the degree of investment in specific complementary assets and the learning effort that will have to be made to use it proficiently. Moreover, a potential adopter is also likely to consider that the new technology is unproven and risky, and that there is a non-negligible probability that he will have to revert to the old technology again, should the benefits not be as high as expected.

Figure 3.8 compares the "objective" utility provided by the new technology with the "subjective" utility provided by the old one, which of course depends on the individual customer's previous decisions. Customer 1, who has made little prior specific investment in the old technology, will be the first to switch to the new one. She will be followed by customer 2, who has made a higher investment in the old technology but is not investing further. The last to adopt the new technology will be customer 3, who has not only made prior investments, but is continuously increasing them.

The phenomenon of localized technological change is generally not so strong as to stop the emergence of a new paradigm, but is generally able to determine a "false start" and delay diffusion by a few years, until technology reaches a performance level that will justify switching costs for the generality of customers.

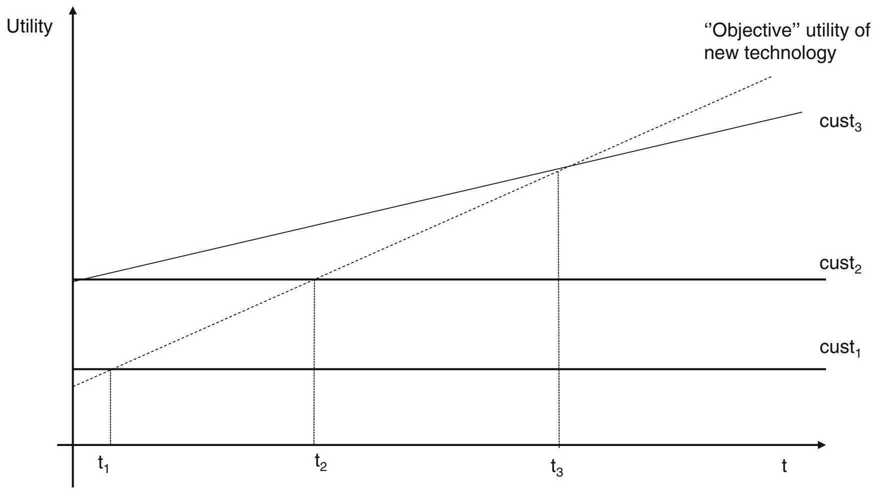


**Fig. 3.8** The impact of localized technological change

### *3.5.3 Appropriability Regimes and Complementary Assets*

A third reason explaining why radical innovation might not end up to be disruptive is connected to the roles of *appropriability regimes* and of *complementary assets* (Teece 1986).

Appropriability measures the degree to which the proponents of the radical innovation can keep the economic value created by this innovation to themselves, instead of having to share it with customers and suppliers and/or being imitated by incumbents. If imitation is difficult, either because of legal protection (see patenting in Chap. 6) and/or because of the tacit nature of technological knowledge, the appropriability regime will be high and disruption by entrants will be likely. Conversely, a weak appropriability regime might not lead to disruption at all, since entrants may quickly and successfully be imitated by incumbents.

Concerning complementary assets, successful innovation requires not only to design new products and services, but also to create the infrastructure that is required to produce them, bring them to the market, provide customer service, and so on. Significant differences may arise from the nature of the complementary assets that make up this infrastructure. These might be generic, specific to the new technology (i.e., given the technology, one must define an asset that will not be of use for other technologies) or co-specific with the technology (i.e., the technology and the asset have to be defined at the same time and are of value only when used jointly).

In the case of generic complementary assets, it will be easy for the entrant to contract these assets from suppliers, enter without significant investment and therefore achieve disruption. In the latter two cases, the specific nature of the complementary assets will either force the entrant to develop the assets himself (i.e., to integrate) or to finance suppliers in order to have them take care of it. In both cases, this raises a significant financial and managerial hurdle to entrants and might lead to sharing the proceeds with asset holders, therefore reducing the attractiveness of the decision.

## 3.6 Strategies for Incumbents, Strategies for Entrants

The previous discussion has broadly explained the reasons because of which radical innovation might, or might not, lead to disruptive innovation. The topic has clear managerial implications that of course depend on whether the firm being considered is an incumbent or an entrant.

The following Table 3.2 draws from the previous discussion and provides a non-exhaustive summary of the strategies that either kind of company might follow when dealing with radical innovation to respectively avoid, or favor, disruption.

**Table 3.2** Strategies for incumbents and strategies for entrants in the context of radical innovation

| Strategies for incumbents | Strategies for entrants |
|---|---|
| Pre-emptively lock customers in your technology<br>Try "killing" the new technology or buy time<br>• improve the old technology<br>• start a price war<br>Segment the market by "needs" and closely monitor (or serve) them all ("incumbent's advantage")<br>Be wary of "sunk cost" and "status quo" traps<br>Jump on the new technology<br>• Listen to "people on the edges"<br>• Bring new champions on your top management team on time and allow some tension between old and new<br>• Fund R&D top-down and/or go for acquisitions (possibly of small firms that are easier to integrate)<br>• Always look for the market and business model that suits current and emerging technology<br>Retreat to a niche or relocate to a different market where you can still use your assets | Find the right beach-head market that is<br>• right for your immature technology<br>• likely to be overlooked by incumbents<br>Make sure that you have enough cash to withstand incumbents' reactions aimed at "gaining some time"<br>Stay away from markets that are over-served and locked-in the old technology<br>Make the right vertical integration choices<br>Carefully look after Intellectual Property Rights to maximize appropriability<br>Be careful if you do not own the required complementary assets<br>Be wary of possible improvements in the existing technology<br>Consider selling your business to an incumbent |

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# Chapter 4
# The Dynamics of Innovation

The previous chapter has focused on the different types of innovation, mostly contrasting the extremes of evolutionary and revolutionary change. Not much has been said about evolutionary change, and on the transformations that take place within a given technological paradigm. This chapter has the aim of covering this topic from a dynamic perspective, taking into account the interplay of supply and demand, and introducing the topic of standards.

## 4.1 The Product Lifecycle—S-Curves and Diffusion

S-curves have up to now been introduced to represent the evolution of a performance indicator against an independent variable such as time or, better still, investment (Fig. 4.1a). However, a second s-curve that roughly follows the performance s-curve can also be drawn, and which represents the *diffusion* of the innovation in the market (Fig. 4.1b).

Diffusion (or *penetration*) can be defined as the fraction of potential users that, at a given time, have decided to adopt the technology. In absolute terms, the diffusion curve represents *cumulated adoption sales*, these being the sales to users who adopt the technology for the first time. Adoption sales usually follow a bell-shaped curve (Fig. 4.1c) that, in mathematical terms, represents the derivative of the diffusion s-curve. In general, adoption sales are only part of overall sales, which also include subsequent purchases made by adopters. In turn, these are given by *additional sales* (i.e., sales to adopters who wish to own more than one such product) and *replacement sales* (i.e., sales to adopters who replace their product with a new one because of wear or obsolescence).

When progressing along the s-curve, it is common to define three main phases, which are respectively termed *incubation* (during which both performance and diffusion still have to "take off"), *diffusion* (when performance and diffusion grow significantly), and *maturity* (when they approach saturation).

Being aware of the current phase in the product lifecycle is very important for companies, since it determines the type of innovations that have to be pursued and the way with which they can be conveyed to the market. During the incubation



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_4

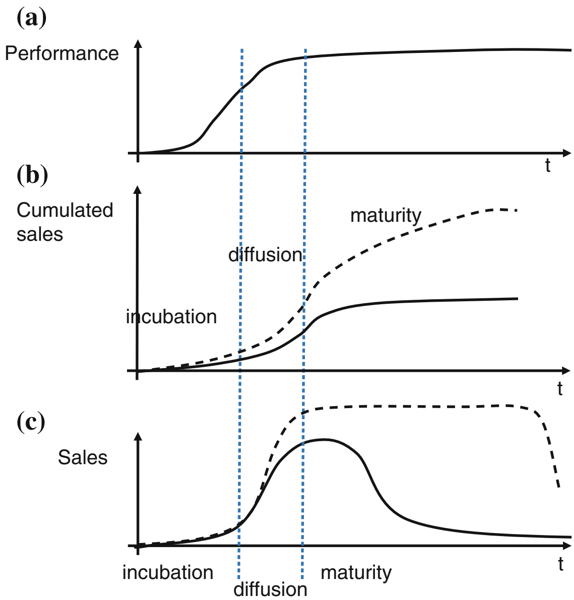


**Fig. 4.1** Performance and diffusion s-scurves

phase, it will mostly be important to master and fine-tune the new technology that is giving birth to the new trajectory. In the diffusion phase, adoption sales are dominant, and the firm will mainly have to convince the market of the utility associated with the new product. During maturity, adoption sales fade away, and the firm will have to rely on additional and replacement sales. Therefore, it will have to focus its effort on convincing the market to increase the product replacement rate. At the end of the maturity phase, the firm will have to expect a period of revolutionary change, which will eventually lead to a new paradigm.

## 4.2 The Incubation Period and the Hype Effect

The incubation period of a technology lifecycle is quite critical and interesting. At this time, technology is still immature and diffusion limited. However, it is likely that awareness of the new technology will be quite widespread, and that the *promises* associated to it may be expressed in exaggerated terms. Practitioners often say that new technology easily suffers from *hyperinflated expectations*, or simply *hype*. A well-known representation of this phenomenon is routinely proposed by the Gartner consultancy for technology related to ICT, in the form of *hype cycles* (Fig. 4.2).

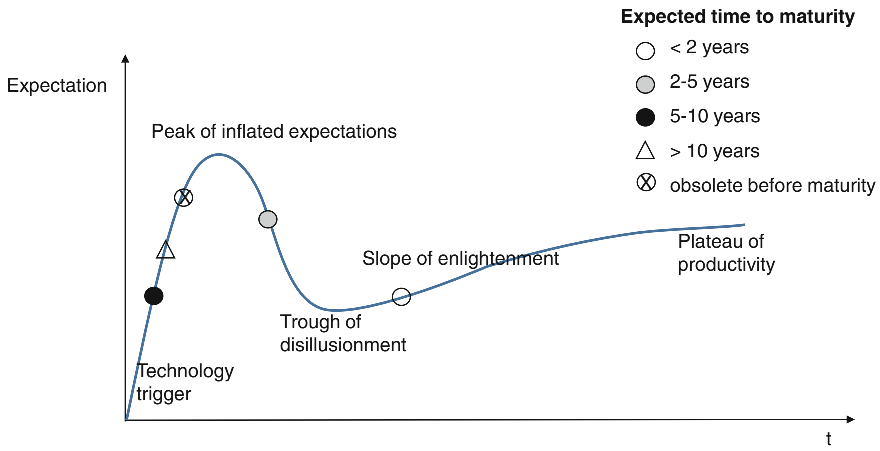


**Fig. 4.2** A simplified representation of a hype cycle

Hype cycles show the current positioning of technologies in the incubation phase, according to five quite imaginatively labeled subphases, along with a forecast of their "time to maturity". According to this representation, soon after a technology appears (*technology trigger*), markets will tend to "fall in love" with it, and expectations will grow until they become unrealistic (*peak of inflated expectations*). When these expectations eventually fail to materialize, the market will quickly lose interest in the technology and dismiss it as a failure (*trough of disillusionment*). At this point, the technology will slowly mature and realistic applications will emerge (*slope of enlightment*), until the technology will finally affirm itself (*plateau of productivity*).

The incubation phase is therefore very important for technological progress, since it allows companies to improve technology in absolute terms, to find applications that are reasonable from a technical perspective and might lead to a profitable market exploitation, to steer technology toward these "real" applications and to raise awareness and confidence in customers.

Directing technology to specific initial applications is a key aspect of innovation strategy. If often happens that a new technology is touted as being "great, because you can apply it to about any industry". While this might be true in the long term, it will not be of any economic value unless firms are able to define a sequence of applications and successfully tackle them one by one.[1]

[1]For instance, RFID (Radio-frequency identification) tags are widely used in supply chains and lead to significant advantages in the traceability of goods of appreciable value (or multi-item packages of goods of lesser value). However, their potential had been overstated around the year 2000, due to unreasonable expectations on the possibility of manufacturing them at minimal cost, which could have allowed placing a tag on the packaging of goods of any value, albeit small.

## 4.3 Diffusion S-Curves and Customer Segments

Diffusion s-curves tell us that customers adopt at quite different moments along the product lifecycle. One can therefore wonder whether customers are all similar to each other, and differences in time to adoption are purely due to chance, or whether customers are individually different in their propensity to adopt, and this propensity determines whether a specific customer will be an early or a late adopter.

Common sense tells us that the latter explanation is the most sensible one, since all human beings and organizations are dissimilar from one another. This leads to the opportunity of understanding the different customer segments that can be found along the product lifecycle.

The most popular segmentation has been proposed by Rogers (1962) and is shown in Fig. 4.3. To this purpose, the diffusion sales curve can be approximated to a normal distribution curve, and then split at the midpoint and at −2, −1 and +1 standard deviations. The resulting segmentation is common to most cases of technology diffusion, and the characterizing features of individual segments are discussed in Table 4.1.

By studying this segmentation, Moore (1991) proposed the existence of a very significant gap (or *chasm*) between the early adopters and the early majority segments. Customers in the former segment adopt because they "look into the future", and are therefore ready to accept a relatively immature technology. Conversely, the latter will only adopt a mature product that fully satisfies them. Therefore, a product that is highly successful with early adopters is likely to be unsuccessful when the early majority segment kicks in. Firms that are market leaders in the early phases of the product lifecycle may therefore fail to understand the new user requirements that characterize the early majority segment, and fall behind when attempting to "cross the chasm".

From a managerial perspective, what constitutes a successful product and what strategy should be followed depends on the segment that is being reached by the diffusion curve. Table 4.2 proposes a few possible recommendations.

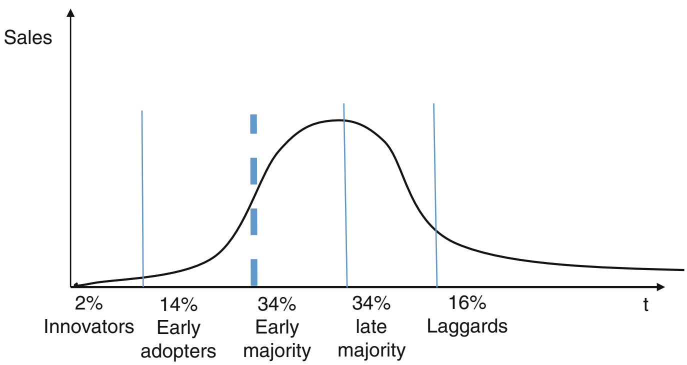


**Fig. 4.3** Market segments along the technological lifecycle

**Table 4.1** The characterizing features of Moore's market segments

| Segment | Typical size of segment (%) | Segment description | Reasons to serve/Not to serve the segment |
|---|---|---|---|
| Innovators (enthusiasts) | 2 | In the case of consumers, innovators are technology enthusiasts, who love technology for its own sake and might even find interest in its shortcomings due to immaturity, since it gives them the opportunity to "play" with it<br>In the case of businesses, innovators are companies with very specific needs, who might even pursue the innovation on their own, because of their peculiar requirements | The segment is very small and therefore not so attractive for large firms from an economic viewpoint<br>Startups might find it interesting as a small beachhead market<br>Innovators also often act as *lead users* (von Hippel 1986) and provide valuable technical feedback |
| Early adopters (visionaries) | 14 | Customers who think the technology will be important in the future and want to gain some early experience with it, even though a direct cost-benefit analysis might suggest waiting some more time<br>Early adopters are not excessively concerned of adopting a technology that is still somewhat immature and/or difficult to use | The segment is *somewhat* attractive because of its size and because it occurs early, thus making it financially interesting<br>Entrants may find it attractive for establishing their brand, since early adopters are also trendsetters and spread "word of mouth" |
| Early majority (pragmatists) | 34 | Customers who decide on adoption, based on costs and benefits. If the technology is immature, too costly or difficult to use, they simply postpone adoption and wait | The segment is interesting to all firms because of its size, and because being active in this segment warrants being active during the rest of the product lifecycle as well |
| Late majority (conservatives) | 34 | Customers who decide on adoption based on costs and benefits, with an added hesitation due an increased perception of risks and/or to localized technological change | The segment is interesting because of its size. Being successful at this stage usually requires having survived the earlier phases |
| Laggards (skepticals) | 16 | Customers characterized by very peculiar needs or hindrances to adoption and are therefore very late | The segment is of marginal interest, because of its limited size and because of the delay with which it occurs |

**Table 4.2** Suggestions for making the product attractive to the different categories

| Making the product attractive to innovators | Making the product attractive to early adopters | Making the product attractive to the early majority |
|---|---|---|
| Understand who beach-head innovators are and their specific needs and find ways to contact them<br>Make sure that initial technical shortcomings can be overcome by users, eventually with some help from the firm<br>Engage in technical dialogue with innovators | Start creating a solid "adoption network" (distributors, complementors, etc.)<br>Start working on ancillary features such as ease of use, design, etc.<br>Define a satisfactory (if not perfect) price-benefit ratio<br>Ensure that the product is reliable and "cool" enough, so that early adopters can start some positive word-of-mouth effect<br>Lower purchasing risk ("get your money back" offers, razor-blade business models, etc.) | Work hard on ease of use, design, etc.<br>Consolidate the "adoption network" (ensure that complementary products and services are made available)<br>Sell as a bundle with other goods with which the user is familiar<br>Make technical features "just good enough", but do not launch over-engineered products.<br>Look carefully at pricing (not too high to discourage, not too low to kill margins)<br>Lower risk in purchasing |

## 4.4 Timing of Entry and Firm-Mover Advantage

Rogers' segmentation allows us to shed some initial light in what is popularly known as *first mover advantage.* This is the competitive advantage that a firm may enjoy by making an early entry in a market. Among the benefits of early entry one can consider:

- **Technological leadership** gained by developing a product and its underlying technology, since the very beginning. This may be particularly interesting during diffusion to innovators, due to the technical dialogue that may occur with them. Technological leadership may also enable firms to protect their inventions with *patents*, which act as barriers to entry against follower firms.[2]
- The possibility of securing **scarce resources**. Examples of such resources may be raw materials, suppliers with specific competencies, key personnel, etc. This scarcity may be due to an actual dearth of such resources, but may also be enhanced by the use of exclusive rights and especially favorable contracts that an early entrant may be able to obtain.
- **Learning effects** due the experience gained in production. As it will be discussed in Chap. 14, it is commonly observed that production cost decreases as a function of cumulated volume, and that this effect is quite significant during the earlier production runs (see Fig. 4.4, where a constant production rate is assumed, and learning curves are therefore traced with respect to time). At time

[2]This topic will be covered in depth in Chap. 6.

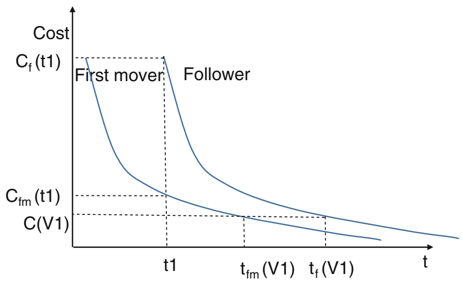


**Fig. 4.4** First mover advantage due to learning effects

*t*1, when the follower enters, the first mover will enjoy significantly lower costs. Taken from another perspective, the follower will narrow the gap with the first mover only after a very significant time.

- **Cash flow** due to margins earned during early sales. These may not only help a company survive, but may be reinvested in the improvement of goods and services, thus accelerating sales and profitability.
- Early entrants, by definition, secure a high **market share** because competitors have not entered yet. Aside from higher margins due to lower competition, this may yield additional positive returns due to customer lock-in, the establishment of brand visibility and loyalty, and the possibility of imposing proprietary standards.[3]
- Early entrants are likely to be the first to reach significant production volumes. This enables them to invest earlier and profitably in facilities that will grant them **economies of scale**. These will allow them cost advantages and act as further barriers to entry.

At the same time, the choice of being a first mover may have some drawbacks, that are associated to the technological and competitive risks involved. More specifically:

- **Research and development** may require higher investment. An early entrant will have to explore the technological landscape and probably end up pursuing a number of unsuccessful technical alternatives. At the same time, she will be unable to learn from competitors' mistakes. In the early phases of the diffusion curve, it will also be difficult to finance R&D with margins from sales, since sales volumes will still be low.
- To be successful, an early entrant will need **complementary technologies, products, and resources** (e.g., supply and distribution channels) that may not

[3]The relationship of proprietary standards and early entry will be discussed in depth at the end of this chapter.

yet be available, or may be inadequate. In many instances, the firm will be unable or unwilling to provide these complementary assets. This being the case, it will have to wait for other firms to do so. However, this will occur only when partner companies (i.e., suppliers, customers, complementors) will find it profitable to do so, and this will usually happen when a sufficient level of diffusion will be reached. Alternatively, complementary assets may be provided jointly with competitors on a cost-sharing basis but—of course—this can happen only when these competitors will actually enter the market.
- **Customer needs** may still be uncertain and unknown. Moreover, needs change when moving from innovators to early adopters, and then jumping the chasm that leads to the early majority. The early entrant will therefore have to work through the process of understanding the needs of different customer segments, sometimes in a relatively short time frame.

Following these concepts, it appears that first mover advantage is not an absolute concept at all, that it might occur or not, depending on the technology and on the firm being considered. For a startup or a relatively weak entrant, it would be unreasonable to delay entry, since getting a foothold in the early diffusion segments is important for financial reasons, to obtain technical feedback and to establish brand equity. However, these are necessary, but not sufficient, conditions for ensuring the firm's enduring success. This will depend on its ability to secure initial funding and to adequately change its product offering when it will have to serve a fast growing mainstream market made up of highly demanding "early majority" customers. Conversely, a company with a strong technology, an established brand and significant financial resources, might decide to wait for other firms to "open the market", skip the first two segments and reach directly for the early majority, with products targeted specifically to that segment.[4]

Therefore, entry decisions will have to be taken by carefully evaluating advantages and disadvantages, and understanding their relevance to the technology, to the firm taking the decision, and looking ahead for the actions that may be taken by competing firms.

## 4.5 The Role of the Dominant Design

When observing s-curves, a question may arise on the shape of s-curves. Why is progress not linear, and what causes the initial incubation phase, typified by a hesitant start, followed by rapid performance growth and diffusion? An answer to

[4]A typical example is the highly successful iPod from Apple, which was a relatively late entrant in the field of MP3 players, and whose features (ease of use, stylish design, complementary music downloading service) were aimed at early majority consumers. Conversely, market leaders in the early phases of the product lifecycle were displaced by the iPod's entry because of their focus on purely technical features that appealed to early adopters, such as disk drive capacity.

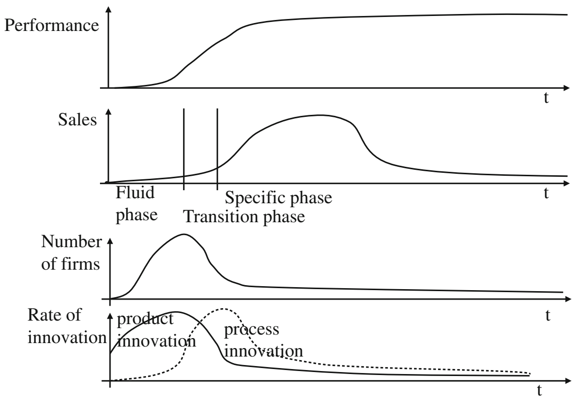


**Fig. 4.5** The Abernathy and Utterback's model

this question can be given by Abernathy and Utterback's theory (1975), which has served as the foundation of a number of other contributions (e.g., Tushman and Rosenkopf 1992). We will initially introduce the Abernathy–Utterback theory in the case of discrete products (i.e., products that are made up of component assemblies and for which it is therefore possible to define an architecture). Later on, the theory will be adapted to the case of continuous products and services.

### *4.5.1 Dominant Designs and the Technology Lifecycle*

The main elements of Abernathy's and Utterback's theory in the case of assembled products are represented in Fig. 4.5.

According to this theory the initial, or *fluid*, phase is characterized by a still immature technology with low performance, for which demand will consequently be low as well. Even though it is difficult to make a profit in this stage, the number of firms entering the industry is high and keeps growing, since the industry is viewed as very promising in perspective. Each firm that enters the market carries a stock of prior competencies and assets that it believes will be useful, and this leads to an extremely diversified range of technical solutions. The rate of product innovation[5] is also very high but—quite surprisingly—does not lead to significant progress. This occurs because firms are not concentrating their efforts in the same technical direction and cannot therefore generate cumulative progress based on the imitation and improvement of competitors' inventions.

At a given point, the industry enters what is termed the *transition phase,* during which one product architecture emerges as the frontrunner, and becomes recognized

[5]The rate of product innovation can be measured through a number of indicators. For instance, one can count the yearly number of granted patents associated to the technology.

as the *dominant design*. The dominant design defines the technical solutions, components and features (i.e., the architecture) that become widely accepted to be the "normal product" in that industry, overcoming other competing designs.

The emergence of the dominant design triggers a sort of avalanche effect, which determines the growth segment of the s-curves. Product performance takes off, as the shared design now allows competitors to imitate each other and generate cumulative progress. In turn, improved performance and a recognizable product induce more customers into adoption, which lifts sales. At the same time, the number of active firms starts to decline, at first because the companies whose assets and competencies do not match the dominant design are forced to either leave the industry, or retreat to specific niches where they can still be competitive. Increasing sales and this initial industry *shakeout* implies that growth rates for a surviving firm will be higher than for the market in aggregate. While this might seem to be good news to them, it also represents a significant challenge, and not all firms will be able to sustain such high growth rates. Among the problems to be faced are raising capital to finance production facilities and working capital, managing a growing workforce and creating a sustainable and formalized organization, finding managers to run it, and so on. Many companies will therefore fail in this effort, thus continuing the shakeout and further stimulating the growth of survivors.

While this process goes on, the lifecycle enters the so-called *specific phase*. During the specific phase, firms strive to compete over cost and quality in a scenario characterized by increasing demand. They therefore shift their focus from product to process innovation. Before the emergence of the dominant design, uncertainty in the product and limited sales discouraged companies from caring too much about production. However, with a now-stable dominant design in the product and a growing demand, it becomes technically possible and strategically important to innovate the process. Firms therefore develop optimized, product-specific and capital-intensive machinery, allowing higher quality and significant economies of scale. In turn, this leads to lower product cost, lower prices, and increased demand. Moreover, it furthers the shakeout, because the new processes determine a *minimum efficient scale**, and this generally leads the industry into an *oligopoly**.

### 4.5.2 The Emergence and Lock-in of Dominant Designs

In the study of dominant designs, one may wonder what are the reasons that lead the market and society into selecting a given technology and architecture, instead of other competing solutions.

A dominant design clearly is one of the key elements that make up a technological paradigm, and a partial answer to this question has therefore already been given in previous Chap. 3. More specifically, dominant designs tend to emerge because of technical superiority leading to better product performance. However, this superiority must not be intended in an "absolute" sense. What matters is the superiority perceived by that first cohort of customers who will lead the adoption process into the transition phase, and who base their choices on their specific needs. Referring to Moore's segmentation, these early customers roughly coincide with innovators (whose needs are by definition *very* specific) and an initial portion of early adopters.

As we will discuss later in this section, a dominant design leads to a lock-in effect. Therefore, it is possible that the choices carried out by these early customers may not be beneficial to society, if one assumes a long-term perspective.[6] Governments may therefore decide to step in the adoption process and steer the selection toward a technology and design that it considers to be socially preferable. As mentioned in Chap. 1, the means for achieving this intervention include regulations, taxation, incentives, and the development of specific and complementary infrastructure.

The dominant design selection process is also driven by the role of specific complementary goods or assets[7] that may facilitate the diffusion of a particular technology and architecture over competing alternatives (e.g., in the early twentieth century, the availability of gasoline as a byproduct of oil cracking and the willingness of the oil industry to invest in the development of a network of refueling stations favored the emergence of the gasoline-powered motor car). One key complementary asset is the existence of a manufacturing technology that—following the Abernathy–Utterback model—may enable the wave of process innovation that will lead the industry to greater efficiency and economies of scale. Since product technologies may have different degrees of manufacturability, it might occur that what seems to be the most promising dominant design might fail prematurely because no manufacturing technology turns out to be available. In such cases, the transition phase of the Abernathy–Utterback model may be made up of a sequence of "false" dominant designs and therefore take a very long time.[8]

A further element that may influence the selection of the dominant design is due to the high degree of uncertainty that is inherent to the process. Given this uncertainty, decision-makers may try to "play it safe" and follow the choices made by those firms, or suggested by those consultants, who are perceived to be market leaders and enjoy a very strong reputation.

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[6]For example, early adopters of motor cars at the beginning of the twenteith century could not (and did not) foresee the long-term environmental and geopolitical consequences of adopting vehicles powered by fossil fuels.

[7]When dealing with relationships between technologies, a commonly used framework has been proposed by Pistorius and Utterback (1997). When both technologies are strictly complementary, they cast a positive effect on each other's diffusion process and we can speak of *symbiosis*. *Pure competition* will happen when the two technologies are substitutes, and each of them hinders the diffusion of the other one. It is possible to have a *predator–prey* effect when a new technology tries to supplant an existing one but, in doing so, it stimulates its growth (e.g., the sailing ship effect discussed in the previous chapter). Conversely, a *prey–predator* effect will occur when an immature technology uncovers a previously unknown market need, but is unable to fully match the required performance, and thus opens the way for a better technology that will displace it.

[8]As of 2014, a similar process may be occurring in the field of electric vehicles, due to issues associated to battery manufacturing, where it cannot be taken for granted that "if volumes go up, costs will go down".

To summarize, the emergence of a dominant design appears to be a somewhat chaotic process, characterized by a high degree of ambiguity and uncertainty. For companies operating in the early phases of the technological lifecycle, betting on the right technological and architectural choices is at the same time not only very important for their future, but also very difficult.

Once a preferred architecture has emerged and the industry has entered the specific phase, the dominant design will tend to remain stable (or *lock-in*) for a very long time. This is mainly due to:

- **Specialization and learning effects**, which allow firms to operate with increasingly higher quality and lower cost. Should alternative and objectively promising solutions arise later on, producers will not find them attractive, because of the larger benefits they gain by sticking with the current dominant design.
- **Economies of scale**. During the specific phase, firms surviving the shakeout will have adopted equipment that is capital intensive and specific to the dominant design. This constitutes a sunk cost that would make the switch to technical solutions that depart from the dominant design unprofitable.
- **Complementary assets**. Once an industry has entered the specific phase, customers, and society at large, will also invest in specific complementary assets that increase the utility deriving from the dominant design. For instance, gasoline-powered cars have led to the establishment of an infrastructure for refueling these vehicles. A technical solution that does not use the same complementary assets (e.g., CNG-powered cars), will therefore be at a disadvantage and find it hard to unseat an established architecture.

Due to lock-in, stability of a dominant design can last decades, and will give way only when reaching a state in which a disruptive innovation becomes able to launch a successful challenge to it. In some cases, lock-in due to complementary assets is so strong that it might influence the evolution of the succeeding dominant design. Therefore, when coming up with a radical and potentially disruptive innovation, firms will not be able to work as if from a clean slate, but may have to come up with a technology that fits well with the previously installed base of complementary assets.[9]

### 4.5.3 Dominant Designs and Vertical Integration

During the fluid phase of innovation, firms face the critical problem of deciding on the degree of vertical integration to adopt. Upstream vertical integration decisions

[9]As an example of this case of strong path-dependency, one can think of LED lights, which "need" to be compatible to the sockets developed by Thomas Edison for light bulbs and fit in existing lamps (and which incidentally come back from the era of candlesticks). By forcing LED lights to fit in a concentrated bulb-like shape, one forgoes much of their potential (e.g., think of the possibility of having flat panels with distributed lighting) and forces to introduce complex solutions for cooling the light-emitting elements.

have to do with the development and/or production of subsystems and components, while downstream vertical integration decisions are concerned with the role to be covered in development of the "supra system" in which the product will operate.[10]

The discussion can start with upstream vertical integration. In the case of products with a relatively low degree of modularity (i.e., components are significantly coupled to one another, so that the design of each strongly depends on the design of the other ones), it is likely to observe a high degree of vertical integration until the dominant design has emerged (Christensen et al. 2002). In fact, it is unlikely that other firms may enter the business of becoming a specialist supplier of an architecture-specific component, unless there is sufficient certainty that this architecture is indeed going to become the dominant design. Therefore, firms working on the final product will have to take up responsibility on component development as well. The opposite may happen for highly modular products (i.e., products whose components are uncoupled from one another, so that the design of each does not significantly influence the design of the others). In this case, components may be developed and produced by independent companies, and simply assembled by the firms who are working on the final product.

A higher degree of vertical integration gives tighter control on components from both a technical and business perspective. However, it also requires a much greater amount of investment, which can make this choice impossible, unless the company is sufficiently well-funded. This strategic choice is always quite difficult, and requires a deep understanding of the product being developed. In some cases, firms might try to develop a "dominant design" out of off-the-shelf components, only to discover that the performance they achieve falls short of what the market requires. On the other side, other firms might undertake the difficult and costly road of vertical integration, simply to discover that other firms were able to operate successfully by using standard components.[11]

When dealing with these issues, one can go beyond looking at specialization in its stricter sense (i.e., on who makes what) and consider at the way knowledge is partitioned between producers and component makers, which can moderate vertical integration choices (Lee and Veloso 2008). In fact, it is possible to achieve results similar to vertical integration if the former develop a sufficient amount of component-level knowledge and the latter some product-level knowledge.

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[10]For instance, a maker of an electric vehicle has to decide whether or not to integrate upstream and deal with the design and manufacturing of batteries, or simply source them from specialist suppliers. Similarly, it may decide to deal with recharging stations (downstream vertical integration with respect to a complementary good) or operate a service business for electric car sharing in urban areas (downstream vertical integration of the product supra system).

[11]In Chap. 14 we will provide a deeper discussion on how all this depends on the type of performance being sought by the market. If the performance the market looks for can be associated to individual components, this implies a higher degree of modularity, and a lower degree of vertical integration will be required. Conversely, if the market looks for performance that is related to system integration, this will require a lower degree of modularity and higher vertical integration.

If one now looks at downstream vertical integration, the problem lies in the value that complementary goods and/or the supra system provide to customers, therefore driving diffusion. If this value is significant, the issue cannot be neglected. However, a firm may decide not to have an active role, assuming that a market for these complementary goods will emerge independently. Alternatively, it may engage in partnerships with "complementors" (i.e., firms producing complementary goods), or decide for full vertical integration and provide these goods. A higher degree of vertical integration requires the financial capability to sustain the related investment. At the same time, a lower degree of vertical integration will be possible only if the relationship between product and complementary assets is non-specific and if there is a clear business model allowing complementors to invest and then gain from their effort.[12]

Tackling a high degree of vertical integration both upstream and downstream may in principle provide the firm with a significant control over the evolution of the technology and of the emerging paradigm. It is however apparent that this choice can not only be financially unfeasible, but also difficult to manage because of the organizational complexity that it entails.

In addition to dealing with this upstream and downstream *technological uncertainty*, firms must also deal with *behavioral ambiguity* in the market (Adner and Kapoor 2010). This ambiguity has to do with customers' actual needs, which at the beginning of the lifecycle are often latent, and with the purchasing process they follow before they decide on adoption, which is likely to be quite convoluted and slow.

It is probably impossible to define a general criterion specifying how a firm ought to split its attention between these two aspects while progressing along the s-curve. Firms should therefore continuously keep a close eye on what is likely to be the current or the upcoming bottleneck that might slow down diffusion, and make realistic evaluations on the likelihood with which they will be able to overcome it. Behavioral ambiguity has the potential of significantly slowing down diffusion of new products. This can have a strong and negative impact on first mover advantage, since a hesitating market "buys time" for imitators and prevents pioneering firms from gaining a significant advantage based on economies of learning.

### 4.5.4 Dominant Designs in Process Industries and in Services

As previously mentioned, the model discussed above holds for discrete products. The model can also be adapted to the case of the continuous process industry and to

[12]More on this will be discussed in Chap. 7, when discussing multiactorial business models.

services.[13] In these latter cases, the roles covered by product and process innovation are simply reversed with respect to what happens for discrete products. The fluid and the transition phase will be characterized by intense process innovation, during which firms experiment alternative technical solutions, and until a dominant design for the process emerges, thus leading into the specific phase. During the specific phase, firms will slow down the pace of process innovation and start working on product innovation,[14] in the attempt of exploiting the previously developed processes and infrastructure.

In this case too, because of the dominant design-specific investments that have been sunk in the process and in related infrastructure, the dominant design will tend to lock-in and remain stable for years. This raises an important trade-off related to the openness, flexibility, and cost of processes. Knowing that infrastructure and processes will remain unchanged for years, if not for decades, decision-makers can on the one side decide to invest a higher amount of money in an open, powerful and flexible process, in view of the many potential products that might be developed and produced on it. However, this is a risky choice, since this variety of products might not occur, thus delivering disappointing financial returns. Conversely, firms may make a conservative investment, but risk that a limited infrastructure may not be able to accommodate future products with high demand. This would lead to significant opportunity costs and to a clear disadvantage against competitors that have made more farsighted choices.

### *4.5.5 Limitations of Abernathy and Utterback's Model*

In recent years, the dominant design model has been subject to a number of criticisms. The first criticism is related to the modular nature of many contemporary products that are based on digital technology. The Abernathy–Utterback model is based on the emergence of a technically and commercially successful product (or process) architecture, which is characterized by a significant degree of rigidity, due to specific investments in tangible or intangible assets. In our days, digital technology is becoming pervasive in many different industries and is characterized by a very high degree of modularity (i.e. products are based on components that are functionally independent and can interoperate through well-specified and non-specific interfaces). As a consequence, digital technology allows firms to develop a very wide variety of products with relative ease, by selecting functional

[13]It must be mentioned that—since observing a process is harder than disassembling a discrete product—studying dominant designs in the process and service industry is somewhat more difficult than for discrete products.

[14]Concerning the service industry, one can think of the many services, such as bills payments and cell phone recharging, that nowadays run on ATM (Automated Teller Machine) systems. These services have been added to the dominant design of ATM systems, which dates back from the '70s, when these new services where not even conceivable.

elements and then combining them together with limited integration work. Therefore, the economies of scale and organizational learning that used to lead to a dominant design might not be found at the level of the product any more but, rather, at the level of their components. So, it might be less obvious for a dominant design to emerge at the level of the product and to determine a traditional s-curve. However, the phenomenon may still be visible at the level of components. Barriers to entry, shakeouts, lock-in effects, and vertical integration phenomena may also become less intense.

A second criticism is related to the emergence of product-services. Given that the Abernathy–Utterback model views assembled products and services as two somewhat opposing worlds, it does not provide a clear interpretative tool for the case of product-services. Research on this subject provides just a few contributions (Cusumano et al. 2006), which suggest that service innovation constitutes a third "wave", following product and then process innovation. One possible hypothesis is that, in a product and service bundle, one of the two will prevail and determine the dominant design and the related lock-in effects, while the other will act as a complementary commodity. Of course, it is not trivial to foresee which of the two elements will have a central and which will have an ancillary role, but interesting clues may be provided by examining where aspects such as standardization (see the following section in this chapter), modularity, economies of scale, and learning might have a greater role.

## 4.6 Innovation Beyond Product Performance

To this point, we have considered product performance, as represented by s-curves, as a proxy to innovation. If one looks at innovation with a broader perspective, it is evident that many aspects other than performance are touched as well. A number of classifications and taxonomies have been proposed over the years to provide this wider view of innovation. What will be proposed in the following, inspired by Keeley et al. (1999) and by Keeley et al. (2013), ought to be taken as one possible proposal, but by no means as a universally accepted classification. Among the additional types of innovation that can therefore be taken into account, one can mention:

- **Product systems**. The value of a product can be enhanced not only by increasing its performance, but also by adding functions. In a number of instances, these functions do not have to be incorporated in the core product, but can assigned to complementary goods that lead to the offering of a more complex "product system". When dealing with a product system, the focal company (i.e. the firm developing the core product) will have a trade-off to solve when deciding on the openness of this offering (Boudreau 2010). By opting for a closed system, the focal firm will integrate horizontally to provide these goods and will therefore appropriate all returns. However, it will also have to make significant investments, including ones in fields that might not fit with its core competencies. Conversely, by opting for an open system, allowing the entry of complementors and the development of what is often called a *corporate ecosystem*, the focal firm will appropriate only part of returns. This might become an attractive option since the overall returns might be significantly higher (i.e., a slice of a very large cake can be bigger than an entire cake of smaller size) and the required investment may decrease.[15] Product systems may also be considered from the perspective of potential complementors. In this case, the strategic choice is related to deciding toward which of the competing ecosystems it should direct its offering. The problem can be quite critical if the investment has to be specific, because of either technical or contractual reasons. In this case, it will have to opt for the ecosystem that is expected to provide the highest overall returns, combining expected margins granted to the complementor and volume.

- **Services**. Services currently make up the bulk of economic value added in developed countries. A number of manufacturing industries have progressively shifted their attention from the simple sale of goods to the provision of related services. In many of these contractual agreements, the producer must manage the product during its lifecycle and is paid on the basis of its actual usage. As examples, photocopiers, passenger cars, and jet engines are ever more leased or rented both to businesses and to consumers. Similarly, telecommunications companies nowadays provide bundles that include connectivity, devices, and content. From the side of customers, the proposition is attractive because fixed investment costs can be transformed into variable operational costs. From the supply side, producers providing a product-service bundle enter a downstream phase of the value chain in which it might be easier to achieve higher and more stable margins, together with customer lock-in. This trend toward *servitization* does not only imply an innovation in business practices, but also a substantial degree of technological innovation. In fact, when shifting from the sale of a good to the provision of a service, the entire product lifecycle (including maintenance, repair, and disposal) has to be internalized by the producer. The producer will consequently see lifecycle events, such as product failure, as a cost, and not any longer as a source of revenue. Therefore, products will have to be redesigned together with a number of complementary systems (e.g., the equipment to be used by field engineers) so that this lifecycle cost is minimized.
- **Channels**. Goods can be sold through different channels, and alternative choices can lead to significant innovations. For instance, one can contrast the sale of computers through a traditional Make-To-Stock (MTS) distribution system, with direct Assemble-To-Order (ATO) sales to customers through an online system.

[15]For instance, one can think of the many accessories that go with smartphones and tablets, from docking stations to in-car holders to travel pouches. A consumer electronics producer can benefit by allowing other specialist firms to produce these accessories for its devices, because they add value and credibility to the core product, thus increasing demand, in a way that the core producer could not match with its own competencies and resources. Consumers would not buy a 1000 € smartphone cover sold by the OEM, but might gladly spend this same money if it comes from a brand that is well known as a luxury leather goods maker.

Innovations of this kind should not be superficially considered as being limited to the business idea. Shifting from MTS to ATO can entail significant innovation at product level, for instance requiring a completely different product architecture that might enable the producer to add or withdraw functions and components without too much effort and with low lead time. In other instances, the shift might require significant innovation at process level (e.g., developing a complex online configurator that supports the sales process, or redesigning the production equipment and the factory layout to make it more responsive to individual orders).

- **Brands**. Marketing experts define a *brand**as a "*[…] feature that identifies one seller's good or service as distinct from those of other sellers*" (American Marketing Association dictionary). This distinctiveness includes technical features and their evolution, which determines an obvious—but sometimes neglected—relationship with innovation. The role of brands in innovation is very important, because customers are usually unable to fully understand the complex technical features and tradeoffs that define a product and its performance, and to make rational choices among them. A brand therefore becomes a summarized and tacit description of these features and trade-offs, that marketing can readily convey to customers. The managerial implication of this concept is that the values inherent to the brand and the objectives toward which the producer directs its innovation strategy must be coherent. Not doing so will result in improvements that the target customer will not be able to appreciate or, worse still, will end up with a confused brand identity.[16]
- **Customer engagement and experience**. The trend toward intangible goods that was discussed when talking about service innovation can be brought to an extreme, when the value that customers perceive in the product or service is highly intangible and emotional. Amusement parks, vacation resorts, videogames, but also automobiles and motorbikes and high-end food become special kinds of products and services in which functionality and technical performance do not matter per se, but in connection to—and as enablers of—customer experience. Innovation is therefore involved with defining new or improved forms of customer experience and in defining the technical elements that allow it.
- **Process**. Process innovation has been defined in previous chapters of this book. Generally, process innovation occurs in a way that is not apparent to customers, who can only observe the outcome, in terms of lower costs and prices and/or improved products or service levels. Process innovation can entail the adoption of new technology and/or changes in the organization and in business processes.

[16]From the side of demand, a customer that is choosing which car to buy will not normally study raw technical data on rigidity of suspensions, interior noise at different engine speeds, and power and torque curves. It is more likely she will look for a brand that encapsulates the right values in the trade-off between an "elegant and comfortable" and a "sporty" car. From the side of supply, a producer of a "sporty" car brand will direct its innovation efforts to enhance the features that are tied to its brand (e.g., acceleration, speed, braking performance, etc.) and will accept some trade-offs in other ones (e.g., comfort, size of trunk, etc.).

Moreover, process innovation can be related to both core and enabling processes of the firm.

- **Network and interfirm relationships**. Innovation in this case has to do with a change in the relationships that the firm establishes with its customers, suppliers, or complementors. In economic terms, this aspect of innovation has to do with vertical and horizontal integration choices. In some cases, these may be aimed at increasing efficiency in the production of ordinary goods and services. In other cases, changing interfirm networks might make it possible to develop and produce innovative products and services that a single firm would not be able to provide by itself.
- **Business models**. Business model innovation can be viewed as a superset of the previously discussed forms of innovation. A company that pursues business model innovation is also likely to change the cost structure and the revenue streams that normally characterize the firms operating in that industry. A typical example is the innovation introduced by low-cost airlines. Practical methods for describing and designing business models and related innovations will be introduced and discussed in depth in the following Chap. 7.

If one considers the many forms of innovation discussed above and their deep impact, it is clear that the problem of managing innovation is not limited to following a sequence of s-curves, with an eye on a single performance indicator. Due to the many dimensions of innovation and strategic options involved, firms can maneuver in the innovation landscape in many different ways. For instance, disruptive innovation—as defined in the previous chapter—might occur because of a process innovation, but without actually causing paradigm shift and moving to a new technological trajectory.[17] Given the variety of aspects with which innovation may be introduced and their potential competitive impact, firms ought to constantly be on the lookout for opportunities as well as for the threat coming from innovating competitors. As stated by Nunes and Breen (2011), this requires a continuous adaptation of operational and managerial competencies, a process that requires quite long time constants. Therefore, this adaptation must be managed proactively, knowing that it is generally too late to react to radical innovation when its impact is becoming apparent on the performance of the firm.

[17]For instance, in the DVD rental industry, Netflix disrupted the pioneer and market leader Blockbuster thanks to a mixture of radical channel, process, and business model innovations (i.e., Netflix used the postal system to deliver DVDs that were chosen by customers on the Internet on the basis of a monthly subscription, while Blockbuster followed the traditional model of having customers come to a store and pay on a "per night" rental basis). Although radical (from a technical perspective) and disruptive (given the impact on the industry), these innovations did not lead to a paradigm shift. The paradigm shift started later, when online streaming technology and related subscription services started challenging the very idea of using physical DVDs as a medium for enjoying audiovisual content.

## 4.7 Standards and the Dynamics of Innovation

The previous discussion has purposely tackled the topic of dynamics of innovation in general terms, without yet dealing with standards. The topic is very important when studying innovation, since standards have the potential of determining the way with which a product diffuses in the market, as well as industry structure.

In some industries, such as ICT and the Internet, competitive dynamics are fundamentally based on standards. Many leading companies in these industries may simply be recognized as the ones who understood the significance of standards better than their competitors and crafted a cleverer strategy around them. In other industries, standards appear to have a minor role. However, this may simply be due to the fact that their relevance has not been fully recognized, and that future leaders in these industries will simply be the first to have successfully played the "standards game".

### *4.7.1 Defining a Standard*

A *standard** can be defined as "*a set of specifications that provide value to the product because of its conformity to the standard*". The definition might sound a mixture between a tongue-twister and a self-fulfilling prophecy, and therefore needs some explanation.

The main idea behind the standard is that a product based on these specifications achieves greater value because of conformity, and not because these specifications define a better product *per se*. To understand if a specification may be conducive to a standard, one can apply counterfactual thinking and ask "*if product X did not follow standard Y, would it be of lesser economic value? If so, would it be because of non-conformity or because of lesser performance?*" A standard is (or could be) present if the answer to this question would be "*yes, it would be inferior, exactly because of non-conformity*". As a matter of fact, a standard may actually define a product that is technically inferior to a non-standard one, yet of greater economic value because of conformity.[18]

This apparently odd phenomenon of value creation through conformity can be caused by one or more of the following mechanisms.

- **Positive network externalities**[19]*. In some cases, compliance to specifications enables the creation of a network linking customers to one another. Every time someone adopts a product that is compliant to the standard, this creates a

[18] A well-known historical example is the VHS* format that—though technically inferior to the Betamax* format—managed to become the standard for domestic videotapes.

[19] In economics, an *externality* occurs when an economic transaction causes an impact on a party who is not directly taking part in the transaction. One can have negative externalities (e.g., pollution created by a driver who buys fuel and drives his car) or positive ones (e.g., the value delivered to a neighborhood when a house owner hires a painter to decorate the façade of a building).

positive externality on the entire stock of existing users, since each of them can now link to the new user.[20] So, the greater the number of users adopting a compliant good, the greater the number of potential links, and the greater becomes the economic value of the good to each user. Conversely, a non-compliant good would not fit in the network and would therefore have very limited economic value.

- **Complementarity with other goods**. Specifications can create economic value by allowing interoperability between complementary goods, such as software applications that run on operating systems, DVDs on disc players and gasoline that can be used to refuel motor cars. A non-compliant good would not be able to interoperate with the complementary good and economic value would therefore be destroyed.
- **Modularity**. As previously mentioned, modular product architecture is characterized by subsystems that can be developed independently from one another, thanks to standardized specifications that define their interfaces and allow interoperability between components. As it will be amply discussed in Chap. 16, modularity, such as in the case of personal computer hardware components, creates economic value by enabling economies of scale and learning, and by allowing users to customize the products they buy.
- **Specific learning**. This aspect is related to user interfaces, such as the icon-based interface that characterizes commonly used personal computer operating systems, or the layout of computer keyboards. A standardized user interface creates economic value, since users will not have to spend time in learning how to use the product and be immediately proficient with it.
- **Economies of scale**. For very simple products, such as screws and pipe joints, standardization enables the use of highly efficient production technology that could not be used if each individual product had to be designed according to a specific application (e.g., standardized screws can be stamped, instead of turned on a lathe).

A standard has been defined "as set of specifications", and does not necessarily represent the product involved in its entirety. A standard is therefore a different concept to a dominant design, which represents the architecture of the product. However, the two concepts are linked, and Table 4.3 summarizes the possible relationships between dominant designs and standards.

In some cases, a standard can define product architecture, and will therefore overlap with a dominant design. One can think of Blu-ray DVD players, where the standard dictates both the specifications and the technical architecture of the disc and player.

[20]Network externalities arise in cases such as computer network protocols, data exchange formats used in electronic documents and e-mails, etc. The value $V$of a network with n nodes is given by the number of potential links that are enabled, or $V(n) = n(n - 1)/2$. When the $(n + 1)$th user joins the network, the value grows to $V(n + 1) = (n + 1)n/2$, with a relative increase in value given by $V(n + 1)/V(n) = (n + 1)/(n - 1)$.

**Table 4.3** Relating dominant designs to standards

| | Dominant design | Non dominant design |
|---|---|---|
| Standard | GSM, VHS videotapes, Blu-ray DVDs | Specifications of the Edison screw<br>Layout of pedals in cars |
| Non standard | Monocoque automobiles | – |

In other cases, the standard may be distinct from (but possibly based on) a dominant design. For instance, in current passenger cars, the pedals controlling clutch, brakes, and throttle are laid out left to right in this same order. This is clearly a standard, because a car with a mixed-up pedal layout would be quite dangerous to drive and therefore of low value. However, the layout of pedals is a specification and not an architectural description, and cannot therefore be defined as a dominant design. What *is* part of the current dominant design of passenger cars is the existence of these three controls and the choice of controlling them with pedals, but this is independent of their layout.

Finally, dominant designs may exist independently of standards. Most passenger cars are currently based on the monocoque* architecture, with the steel body providing multiple functions such as aesthetics, rigidity, aerodynamic performance, and protection to occupants. This is a dominant design, but not a standard, since an alternative architecture (e.g., based on a chassis such as in commercial vehicles, or on a space frame like in sports cars) can be better or worse, but only because of its intrinsic performance. It would not be possible to state that an alternative design is worse "because it is different from the usual monocoque".

### *4.7.2 How Do Standards Arise?*

The previous discussion has presented five economic mechanisms through which a standard can generate economic value. A standard with a high market share will give rise to a large network, attract a higher number of suppliers of complementary products and components, and lead to greater economies of scale and learning. Regardless of which of these mechanisms are in place, the amount of economic value essentially depends on the size of the customer base. Therefore, a standard with significant market share will generate greater economic value than a technically superior standard with low market share, and the maximum possible value will come from a standard that completely dominates its market. As a consequence, if multiple alternative standards emerge, a selection process will start, in which weaker standards will progressively fail until a single one emerges as the winner (i.e., a *winner-take-all* competition).

When the winning standard will have emerged, the market will obtain a significant amount of economic value, but will also be *locked-in*, since switching to a new standard will become very difficult and costly. The economic value created by the dominating standard will be so high, that only a very significant performance increase would convince customers to switch to a new standard.[21]

In this *winner take all* environment, producers must decide whether to *agree* on a common standard, or compete against each other in a *standards war* and try to impose their own solutions as a *proprietary* and *de facto* standard, with the potential of becoming monopolists with an attractive long-term perspective, due to lock-in. The decision is a highly strategic one for the companies involved (Ullmann-Margalit 1977; Shapiro and Varian 1999; McNichol 2006).

By starting a standards war, competitors engage in a very risky path. They try to become monopolists, which would of course provide quite attractive returns. At the same time, they bear the risk of being excluded from the market, should their standard lose. Moreover, a standards war is usually quite costly from a financial perspective. As we will discuss in the next subsection, winning a standards war requires specific strategies that significantly reduce profitability, at least until the war is ended. In addition, when a standards war starts, customers usually hesitate in buying the new product, because they want to avoid choosing the "wrong" one. By deferring adoption until the situation is clearer, diffusion slows down, and this too contributes to making the financial return less attractive for producers.

Conversely, in case of agreement (for instance, by carrying out active cooperation in the relevant Technical Committee of a standardization body such as ISO*), competitors follow a low-risk path. By avoiding the standards war, they do not risk being excluded from the market, but at the same time they give up the opportunity of becoming monopolists. The agreed standard will in principle become a common playing ground for all players in the market, and the underlying technology will not provide competitive advantage.[22] Finally, the agreed standard will have a faster diffusion in the market, and the financial return will therefore be higher for the industry as a whole.

The choice between agreement and competition between standards depends on the risk aversion of the players, industry structure, and on the existence of mechanisms and organizations that may support the process of finding an agreement. An industry with a high number of recognized players of comparable strength will be quite likely to look for agreements, since the risk and cost of starting a standards war will be perceived to be much greater than the expected monopolistic returns. Conversely, an industry with very few competitors, or undergoing continuous entry of new players with different strengths, might find it difficult to find an agreement. The technological nature of the standard may also matter. If the alternative

[21] An often cited example is related to the QWERTY* standard for typewriter (and now computer) keyboard layouts. The standard had been designed around 1870 in order to minimize the likelihood of typebars jamming. When improved designs for typewriters made this requirement obsolete, other improved and faster layouts were not able to unseat the QWERTY standard, because typists' ability with the standard keyboard created lock-in.

[22] In practice, market share will depend on the capability of each firm of developing attractive products based on the agreed standard. So, market share might be higher for the companies that managed to steer the standard closer to their technological base and to their competencies.

standards are based on the same technology (i.e., think of the shape and pin layout in a connector for electronic circuits), it will be easy to find some kind of agreement. Conversely, if the competing standards are based on different technologies and each player has made a specific investment on one such technology, agreeing becomes close to impossible. Any agreement would in fact imply choosing one technology over the other ones, thus favoring one company and placing the others at a disadvantage.[23]

Policymakers usually follow standardization processes with great attention, especially when industry players lean toward starting a standards war. From a societal perspective, standards wars are not generally desirable. They are costly, since losing companies waste a significant amount of financial resources. They slow down the diffusion process and therefore reduce the utility that society can draw from a quick adoption of the innovation. They have the potential of leading to entrenched monopolies. Finally, the risks and returns inherent to a standards war create a huge incentive for companies to launch products based on proprietary standards as soon as possible, in the quest to be the first player to achieve critical mass and therefore make it easier to attract subsequent customers. Firms will therefore tend to launch products even if their technology is not yet completely mature. If this strategy works, the market will be locked in an immature technology and unable to switch to an improved one.

Therefore, when spontaneous agreement by industry players is not possible and if policymakers are wary of the risks of de facto standardization following a standards war, standards may be imposed *de iure* (i.e., by law). In this case, the public authority sets the standard—usually by asking for some form of technical cooperation with the industry—and finds a way to inhibit the diffusion of the product until the standard is defined. This process usually requires some kind of authorization procedure with which the government may effectively force producers to wait before launching (e.g., telecommunication standards require a license for using a public good such as the electromagnetic spectrum, vehicles must be licensed for roadworthiness, etc.).

### *4.7.3 Strategies for Imposing Proprietary Standards*

When a company is involved in a standards war, making its proprietary standard win requires a very specific approach to product strategy. Being a winner-take-all process, strategic mistakes can cost very dearly, and the firm must therefore not only make the

[23]This was the case of the standards war between Sony's Blu-ray and Toshiba's HD-DVD technology. The technological choices behind the two were completely different, and it would have been irrational for the companies to agree on any one. For Sony, agreeing over HD-DVD would have implied writing off the very significant investment (a sunk cost!) made to develop Blu-ray technology. For Toshiba, agreeing over Blu-ray would have required costly licensing of Sony's intellectual property.

right strategic choices, but also execute them correctly. The following discussion provides a list of possible strategies that have proved themselves successful:

- The first strategy is to be the first firm to achieve a critical mass of users, so that future customers will find greater utility in adopting the leading proprietary standard over competing ones, thus initiating a positive feedback mechanism. Ways to achieve this include:
  - Accelerating time-to-market and being the first firm to launch a product, even if some further developments might lead to better performance;
  - Using a *penetration pricing**[24] strategy, which may require selling the product below marginal cost or even giving it away for free, with the perspective of recouping losses thanks to future economies of learning, and after a monopolistic condition has been reached;
  - Using a market segmentation and *price-discrimination* strategy*,[25] so that all market segments are induced into adopting the firm's products from the very beginning of the diffusion curve;
  - Licensing the product to competitors. This way, the firm can increase supply of its proprietary standard without having to invest in the necessary assets (e.g., production equipment, salesforce, etc.) and can steer licensees away from pursuing their own—or other competitors'—standards. By following this strategy, the licensor forfeits being a monopolist for as long as the licensing agreements are valid. However, it might choose to stop renewing them when the standards war has been eventually won and licensees' help is no longer needed, thus becoming a monopolist[26];

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[24] Penetration pricing means selling a product at a low price in order to stimulate demand, and increasing it when it becomes possible to do so. A penetration pricing strategy can be made explicit, i.e., through publicly revealed prices, or implicit, i.e., by informally granting deep discounts, or even allowing free giveaways (for instance, a software company may allow some degree of piracy in order to increase diffusion of its product). Penetration pricing runs counter to a *price skimming* strategy, with which a company would start with a high price and progressively lower it. Price skimming is a very popular strategy, since it allows achieving high margins thanks to inter-temporal price discrimination (i.e., the product is sold at a high price to customers with high willingness-to-pay and progressively to customers with lower reservation prices). Moreover, it allows companies to keep a constant margin, since prices will follow declining production costs. However, a price skimming strategy would be suicidal for a company trying to impose its proprietary standard.

[25] A price-discrimination strategy implies providing different versions of the same product, targeted at corresponding customer segments, starting from a low-cost entry-level version with reduced performance, up to highly priced high-end versions with enhanced performance. In the software, internet and media industries, this is often referred to as a *freemium** strategy. In such cases a basic product is given away for free in order to promote diffusion, but customers who need additional features and have a higher willingness-to-pay must pay a fee in order to use the "premium" versions.

[26] Antitrust authorities are nowadays quite wary of this kind of behavior. In general, they do require that the technology behind proprietary standards is made available to competitors on reasonable terms, that licenses are not opportunistically withdrawn, and that renewal is not refused at expiry.

- Exploiting the so-called word-of-mouth effect between adopters and potential adopters, thus stimulating *viral* or *epidemic* diffusion in the market[27];
- If the standard lends itself to generating a two-sided market*,[28] making sure that diffusion progresses evenly on both sides, so that both types of customers are attracted to the standard thanks to the number of customers of the other type. Similarly, a firm may support the provision of complementary goods either by itself or by relying on complementors.

- A second commonly used strategy is to try creating a high market expectation that the proprietary standard will win, so that customers will be drawn in adopting it *in lieu* of competing ones. Companies having an established reputation as market leaders and tough competitors have the upper hand in this kind of strategy. However, other companies can attempt it too, by crafting a careful communication strategy, and working on key influencers (e.g., the media, consultancy companies, salespeople, etc.). In fact, standards wars are often won by the firms who manage to bring the players who operate closer to customers to their side.
- A third strategy is based on creating an irreversible commitment to a specific technology and standard, based on a significant specific investment that therefore becomes a sunk cost. This action implicitly signals to competitors the readiness of starting a price war, should a competing technology arise.[29] The threat may be effective even if the company simply announces the investment. Of course, the announcement must be followed by facts since—failing to do so—the company will lose its credibility and will also not be able to repeat the strategy again.
- A fourth strategy has to do with working on the lock-in effect. A firm trying to entrench its standard will try to increase customer lock-in by supporting the purchasing of specific complementary goods and helping them become

(Footnote 26 continued)

However, a licensor may deceive this requirement by making small upgrades to its technology, in a way that new agreements are required. Negotiations could then be artfully slowed down, and it would not be easy to prove that the licensor is "dragging its feet" and is not sincerely trying to settle a complex deal.

[27]The word-of-mouth phenomenon will be covered analytically in Chap. 13.

[28]For instance, a smartphone operating system creates a two-sided market between customers and application developers. By increasing the number of the former, it becomes more attractive for the latter to create applications for that specific operating system. Conversely, the availability of many applications makes the operating system more attractive for customers. Other two-sided markets are the many online marketplaces linking buyers and sellers, such as eBay, Amazon, AirBnB, etc.

[29]Suppose company X makes a non-recoverable investment $I$ in developing a specific technology, with the expectation of producing a volume $V$ at a variable cost $VC$. In normal conditions, X would ask a price $P > VC + I/V$ in order to recoup the investment. However, since the investment is a sunk cost, should a competitor Y try to enter the market, X would find it rational to start a price war and lower the price to $P > VC$. In turn, by knowing this would be a rational behavior for X, it would not be rational for Y to make a similar subsequent investment, knowing that it would never be recovered. This behavior is similar to the Hernando Cortez's military strategy of "burning boats on the beach".

proficient users of the standard. Conversely, a firm trying to fight an established standard will have to decrease customers' switching costs. This can be done with actions such as ensuring compatibility with the old standard, offering discounts aimed at *competitive migrations*, etc.

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# Chapter 5
# Fundamentals of Technology Forecasting

The previous chapters have looked at innovative phenomena from the privileged perspective of the management scholar, commenting on history after the facts have unfolded, trying to come up with rational explanations and to find recurrent patterns in s-curves and similar representations. However, practicing managers find themselves in the unenviable position of having to make critical decisions while events are happening and while there is substantial uncertainty on the direction and the values that will be taken by variables such as prices, demand, and performance indicators.

Technology forecasting* is a discipline that tries to provide some support by using forecasting principles to the dynamic behavior of technology and innovation. It is a specialist discipline, and it is usually practiced by scholars and by analysts working in specialist consultancy firms. However, managers who will never develop technology forecasts themselves will very often be readers and users of analyst reports. This makes it worthwhile to dedicate a short chapter on the main approaches being used, so that readers may become acquainted on the techniques with which they are developed and also on their limitations. Readers interested in the subject may refer to specialist sources, such as (Martino 1983 and Firat et al. 2008).

## 5.1 The Case of Revolutionary Change

Previous chapters have highlighted that technological progress follows a sequence of evolutionary and revolutionary phases. While the former exhibit a substantial degree of continuity, the latter correspond to significant discontinuities. Making a forecast of discontinuous events is intrinsically difficult, especially when it has to do with phenomena characterized by strong social content such as innovation. In such cases, past experience cannot provide a solid basis on which future phenomena may be anticipated. More specifically, it is not feasible to use statistical methods to extrapolate future trends.

Therefore, the only approach available to achieve a forecast of future events characterized by discontinuity is to ask experts to provide their own vision of the future. The kind of insight being asked for can be highly qualitative and open-ended



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_5

(i.e., "please tell me under what circumstances it is likely for technology X to emerge in the future") or defined in more precise and quantitative terms (i.e., "please provide a probability estimate that, by the year 2020, technology X will have reached a performance of Y").

When performing this kind of exercise, it is customary to interview *panels* made of multiple experts coming from different areas and disciplines, and try to see whether a consensual view emerges. Analysts may interact with experts by organizing rounds of individual interviews, workshops requiring the physical presence of the entire panel, or online debates and fora in which experts interact at a distance. However, it is very unlikely that a consensus will be spontaneously reached. The obvious reason is that, when trying to imagine a medium-long term vision of highly uncertain events subject to discontinuity, experts will rely on their individual experience and background and neglect potentially relevant factors that fall outside the scope of their attention. In addition, experts will often tend to express somewhat extreme views, partially to emphasize their point, and partially to express their ego and "stand out of the crowd".

To steer discussion toward a consensual view, analysts often use the so-called Delphi method*, or some of its variants. In the basic Delphi method, multiple rounds of discussion are carried out. Quite often, experts are asked to provide a quantitative estimate for a future state. At each round, analysts focus on the experts who provided the most extreme values, and ask them to write short statements explaining their reasons to the other participants. Experience shows that either these explanations are convincing and allow moving the estimates of the majority of the panel toward the extreme, or these "extreme" experts will soon fall back to the intermediate values shared by other members. In any case, variance in the estimates will tend to decrease round after round. Analysts will therefore carry out the exercise until they feel that variance is acceptable and that an additional round would be annoying to ask for, without substantially reducing variance further (Fig. 5.1).

When examining a report based on panel interviews, the reader should therefore understand what methodology was followed (e.g., in the case of individual interviews, were extreme views taken into account and how?) and the composition of the panel, checking whether relevant fields of expertise were all included or whether some were omitted.

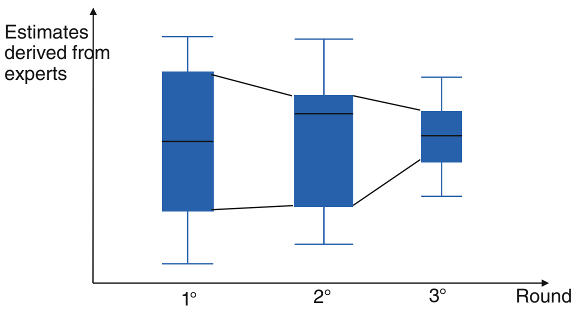


**Fig. 5.1** Expert estimates in the Delphi method

## 5.2 The Case of Evolutionary Change

While interviews to expert panels are used when working on discontinuities, quantitative methods from statistics and time-series analysis can be used when dealing with evolutionary change. As mentioned multiple times, the prevailing evolutionary phenomenon in innovation is well-represented by an s-curve, or logistic curve. In general, a complete s-curve representing the evolution of a parameter $v$ (such as a performance indicator) over an independent variable $t$ (such as time) corresponds to a differential equation in which the instantaneous speed of variation of $v$ is proportional to the same level $v$, with a saturation effect given by an inverse quadratic relationship to $v$. In algebraic terms:

$$\frac{\mathrm{d}v}{\mathrm{d}t} = kv - bv^2 \tag{5.1}$$

By solving the differential equation, the evolution $v(t)$ is as follows:

$$v(t) = \frac{\frac{k}{b}}{1 + \mathrm{e}^{-k(t-t_0)}} \tag{5.2}$$

Equation (5.2) represents what is also commonly known as a logistic curve, where $k/b$ is the asymptote (or the limit L) of the s-curve (Fig. 5.2).

When trying to represent an entire s-curve by using the logistic model, a number of problems arise in identifying parameters. To work on a time series, the model has to be transformed in a 2nd-order finite-difference Eq. (5.3):

$$v_{t+1} = (k+1)v_t - bv_t^2 \tag{5.3}$$

One way with which parameters $k$ and $b$ may be identified is to view the finite-difference Eq. (5.3) as an autoregressive formulation in which $v_t$ and $v_t^2$ are the two independent variables. With this assumption, multiple linear regression analysis

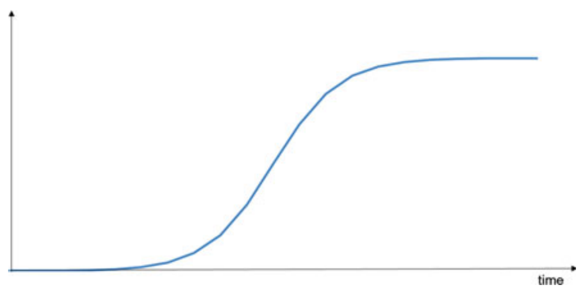


**Fig. 5.2** The logistic curve

can be carried out to identify values for k and $b$. This approach is very weak from a statistical point of view. Equation (5.3) is not linear and, by treating it as such, one neglects the obvious collinearity between $v_t$ and $v_t^2$. In practice, it is possible to use this shortcut if one has enough data points and if the s-curve has evolved for a sufficient time. Conversely, it would be risky to use the approach if the s-curve has just started. In this latter case, minor measurement errors would lead to large swings in the values of the parameters identified through linear regression and the resulting forecasts would be quite unreliable.

An alternative approach is to transform Eq. (5.2) in (5.4)

$$\frac{v_t}{L - v_t} = e^{k(t-t_0)} \tag{5.4}$$

where $L = k/b$ and then into (5.5):

$$\ln\left(\frac{v_t}{L - v_t}\right) = -kt_0 + kt \tag{5.5}$$

This approach requires an *ex-ante* estimate of the limit of the s-curve L, and works fairly well for short data series. This ex-ante estimate can be obtained through expert interviews, as in discussed in the previous subsection.

When one is operating in the early stages of a phenomenon, it might be better to make reliable forecasts on a relatively short horizon than highly uncertain ones on the entire evolution of the s-curve. In such cases, it is possible to use exponential and even linear growth models.

The differential equation that represents an exponential growth model is (5.6):

$$\frac{dv}{dt} = kv \tag{5.6}$$

which can be integrated to yield the Eq. (5.7):

$$v(t) = v_0 e^{k(t-t_0)} \tag{5.7}$$

Parameters for (5.7) can be identified by applying linear regression to the finite difference Eq. (5.8):

$$\ln(v_t) = \ln(v_0) - kt_0 + kt \tag{5.8}$$

As shown in Fig. 5.3, the exponential model is a good representation of an s-curve, until its inflection point is reached. After that point, it obviously provides a misleading forecast. Exponential growth models are often expressed in verbal terms

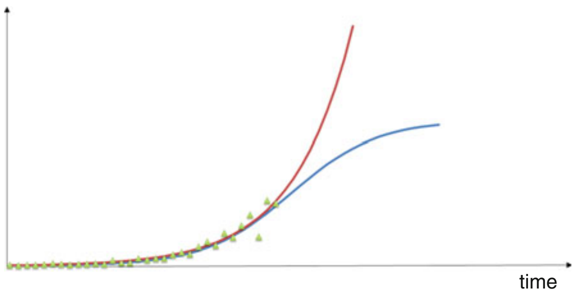


**Fig. 5.3** The exponential approximation

in statements such as "*technology X will see its performance increase by y % per year for the foreseeable future*". When reading such statements, managers should be well aware of the "foreseeable future" part of the sentence. This limit is represented by the inflection point and—when that point will have been reached—growth in the s-curve will slow down in a way that is roughly symmetrical to what has happened up to that point. A rough rule of thumb for figuring out the position of the inflection point is to view it as the moment at which the s-curve will have reached 50 % of its limit L. If one can rely on expert opinion about this asymptotic value, it is possible to make an educated guess on the time at which the exponential growth model will cease to be valid.

If the number of data points is very small, it is possible to use a linear model. In this case, the differential equation is (5.9)

$$\frac{\mathrm{d}v}{\mathrm{d}t} = k \tag{5.9}$$

Which can be integrated to yield the Eq. (5.10):

$$v(t) = v_0 + kt \tag{5.10}$$

Parameters for (5.10) can be identified by using the finite difference Eq. (5.11):

$$v_t = v_0 + kt \tag{5.11}$$

The linear growth model is the simplest one and can obviously be used for a short-term forecast, but it has the advantage of being usable even with a very short time series. When referring to s-curves, it is possible to think of three linear models being used, one for the incubation period, another one for the growth period, and the last one for the maturity period (Fig. 5.4).

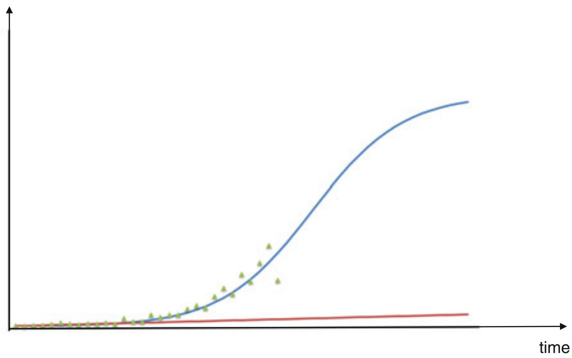


**Fig. 5.4** The linear approximation

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# Chapter 6
# The Many Approaches to Innovation Strategy

This first part of the book has considered innovation mainly as an economic phenomenon, and has looked at it from the high-level perspective of an industrial sector and of society at large. Later we will enter another level of analysis, in which we "take the driving seat" of a company to define its innovation strategy.

Now, what is an innovation strategy, and how can it be defined? Drafting an innovation strategy obviously means creating a plan describing what kind of innovations the firm will pursue in the planning horizon, together with the means for doing so. Given its significant and wide-ranging implications, innovation strategy will be an integral part of strategy at corporate level. We can therefore define innovation strategy as the "*part of corporate strategy that has to do with the way with which the firm will pursue innovation in its many possible facets*".

The formulation of corporate strategy can follow a number of approaches and schools of thought. Choosing among these approaches has to do with the specific type of company, its attitude, the environment it operates in and the availability of information that decision-makers can rely on. Therefore, given the close link between corporate strategy and innovation strategy, there will not be a single way for defining the latter.

This not being a textbook on corporate strategy, we will limit ourselves to a quick description of the most popular approaches to corporate strategy, and outline the way with which they relate to innovation strategy. Specifically, we will discuss the product portfolio, the competitive advantage and the resource-based approaches and provide some comments on so-called shaping strategies. When discussing competitive advantage, a short section will also be dedicated to the management of *intellectual property rights* (IPR).

## 6.1 Which Approach Should Be Followed When Thinking of Innovation Strategy?

Firms differ substantially when we look at the way they approach strategy, and even more so when we observe their attitude toward innovation. In Miles and Snow's (1978, 1984) classical distinction, companies can act as *prospectors*, *analyzers*,



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_6

*defenders* and *reactors*. Prospectors are the ones who proactively and aggressively pursue opportunities for change and innovation, both incremental and radical. Defenders are firms that settle in a somewhat stable industry and avoid engaging in diversification or innovation, if not of the incremental type. Analyzers are somewhat in the middle between the previous two, and generally engage in diversification or radical innovation only after extensive reflections, and usually not as first movers. Finally, reactors are the most conservative firms, and accept change only when external pressure to change becomes impossible to resist. The membership of a firm to one of these classes is embedded in the culture shared by its shareholders and managers and throughout the organization. Therefore, pursuing an innovation strategy that is alien to this prevailing culture is bound to be very difficult, and will require an extensive effort to change the culture itself.

A second perspective that can help understand which approach to strategy formulation is coherent with a given firm, has to do with the stance that the firm has toward uncertainty, which of course is a key aspect to be considered. Following Fig. 6.1, companies may have different attitudes with respect to their capability to foresee where their environment is heading and in their capability to actively contribute to such change.

In the case of firms who perceive a high capability to predict future trends, but a low capability to influence them, strategy takes the form of planning. After analyzing these trends, the company will define a sequence of actions that leverage on its existing assets and involve future investment, with the objective of maximizing financial returns. The portfolio management approach and—to some extent—the competitive advantage approach lend themselves quite well to this type of firm.

When a company perceives a low capability to both predict and influence the future, strategy will take the form of adaptation. The typical approach to corporate strategy will be resource-based, and the firm will progressively move in the competitive landscape by leveraging and pivoting on its assets and competencies.

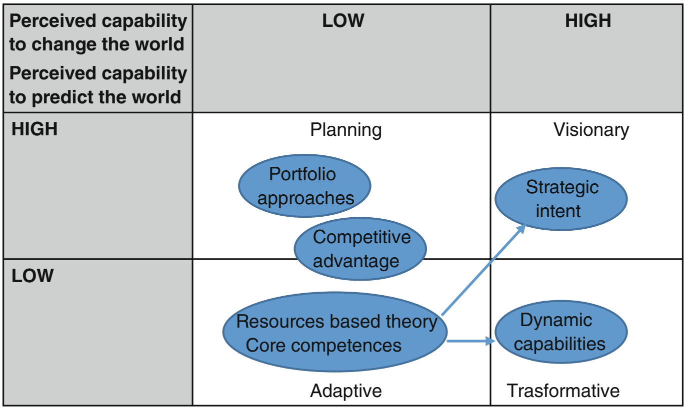


**Fig. 6.1** The relationship between approaches to strategic management and uncertainty

Firms who perceive a low capability to predict future trends, but feel confident of being able to exploit opportunities and play a major role in determining them, will view strategy as transformation. They may use the dynamic capabilities approach, which consists in working on current competencies and building new ones that fit the future scenario, thus allowing proactive moves in the competitive environment.

Finally, a few firms may exhibit a high confidence in foreseeing future scenarios, simply because they believe that the future is going to be determined by their own actions. In such cases, strategy is based on a visionary approach, and will follow so-called shaping strategies (Hagel et al. 2008).

The strategic stance taken by a specific company will depend not only on its internal culture, but also on its nature and its position with respect to the industry. A fast-growing startup operating in an emerging industry might coherently pursue a visionary strategy, while a large and diversified multinational might find it rational to follow a much more cautious planning or adaptive approach.

## 6.2 Innovation and Product Portfolio Management

The product portfolio management approach views the firm as a collection of *business units** (BUs) and/or product families, directed to a variety of markets. Strategic decisions are connected to entry (i.e., opening new business units, launching new products, and entering new markets) or exit (i.e., closing business units down, taking products out, or exiting markets). A metaphor for the portfolio approach is the typical card game, in which players routinely discard an unwanted card and pick a new one from the deck, trying to maximize the value of the set of cards they hold in hand.

From a theoretical perspective, the product portfolio approach considers the firm as an internal capital market, in which cash flow from mature and successful products finance the development of up-and-coming ones.[1] The best-known method related to this approach is the BCG matrix (from the Boston Consulting Group, the consultancy firm that introduced it in 1970), which is depicted in Fig. 6.2. The BCG matrix is generally represented as a bubble chart, in which each BU is a circle

[1]This approach is typical of highly diversified firms, or *conglomerates** and contributes to explaining their existence. In fact, why should an investor prefer buying a share of a conglomerate, and take ownership of the underlying activity portfolio defined by corporate managers, instead of asking an investment fund manager to pick shares and create a financial portfolio of smaller and more focused firms? The standard answer to this question (Kopp 1968; Faulkner and Campbell 2006) is that financial markets are imperfect. Lack of information and a high degree of uncertainty place a corporate manager in a better position to make investment decisions than a fund manager, especially when dealing with emerging business opportunities. A second answer is that there can be synergies between the business units of a conglomerate, together with common assets such as a well-known brand, reputation, and management skills. On the other side, analyzing a conglomerate is difficult for outside investors. Because of this ambiguity, the stock-market valuation of conglomerates is often discounted with respect to the sum of the valuations of their business units.

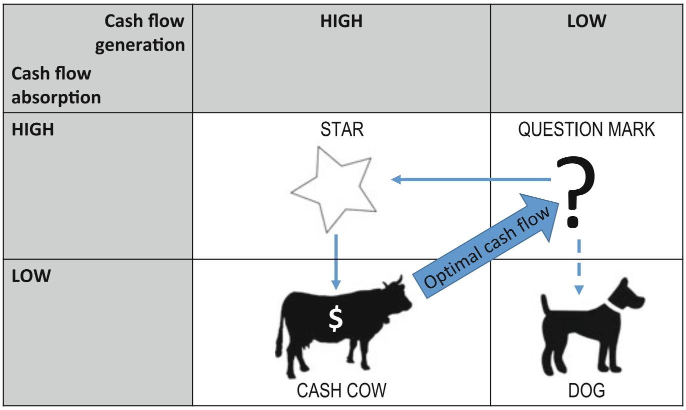


**Fig. 6.2** The BCG (Boston Consulting Group) matrix

whose diameter is proportional to the economic importance of the unit (e.g., sales). The two axis of the chart are associated to cash flow generation and cash flow absorption of each BU.[2]

A fledgling and early stage business that requires significant investment, but is still unable to generate any cash flow will be considered to be a *question mark.* A BU will be considered to be a *star* if it is at an intermediate stage, where it does generate cash, but still requires further investment. A *cash cow* will be a successful, cash-flow positive and mature business. Finally, a *dog* is an unsuccessful business that does not require investment, but does not return significant cash flow. Strategic decisions consist in selecting a "balanced" portfolio of BUs with no dogs, a set of question marks and stars offering opportunities for future growth, together with some cash cows providing dividends to investors and adequate financing to question marks and stars.[3] A portfolio leaning too much on the former or on the latter might, respectively, have problems in securing financing for growth, or in ensuring future competitive advantage.

The relationship between the BCG matrix and innovation strategy should be quite evident to readers. In fact, the cells in the matrix are closely related to the

[2]In practice, one must use proxies for cash flow generation and absorption. For the former, it is common to use relative market share (i.e., the market share of the BU divided by the market share of the largest competitor), since this provides a rough indication of profitability. For the latter, sales growth rate is generally used, since a growing business must generally be supported by adequate investment.

[3]What constitutes a "balanced" portfolio depends on shareholders' preferences. A startup company is likely to be made up of a single question mark, and venture capital shareholders will explicitly require this, given the mandate they have received from their own investors (i.e., to look at rapid growth in valuations and not at dividends, and to diversify risk by investing in a number of individually well-focused startups). Conversely, a large conglomerate that has traditionally treated its investors to a steadily rising flow of dividends will need to have many cash cows and just enough question marks and stars to ensure sustainability of the business for the future.

s-curve representation of innovation, with question marks being products belonging to the incubation phase of the curve, stars to the growth phase, and cash cows to the maturity phase. When following the BCG approach, innovation strategy therefore appears to be directly coupled to corporate strategy. However, this innovation strategy is spelt out at a very high level of abstraction, since it does not go deeper than the decision to enter, invest, and exit businesses. The way with which the firm or its business units should operate within these decisions is instead neglected.

For the record, similar approaches to the BCG matrix have been proposed over the years, such as the McKinsey/GE matrix and the A.D. Little matrix (Fig. 6.3a and b respectively). In these cases too, there is a connection between the mapping of products and business units with their positioning on the innovation s-curve. In fact, the two axis of the A.D. Little matrix are the "Position on the life-cycle", which explicitly relates to technological s-curves and the "Competitive positioning of the firm". The "competitive positioning" axis can also be found in the McKinsey/GE matrix, which uses "attractiveness of industry" as the other axis. "Attractiveness of industry" is related to s-curves too, since emerging technologies and markets are usually considered to be more attractive than mature or declining ones.

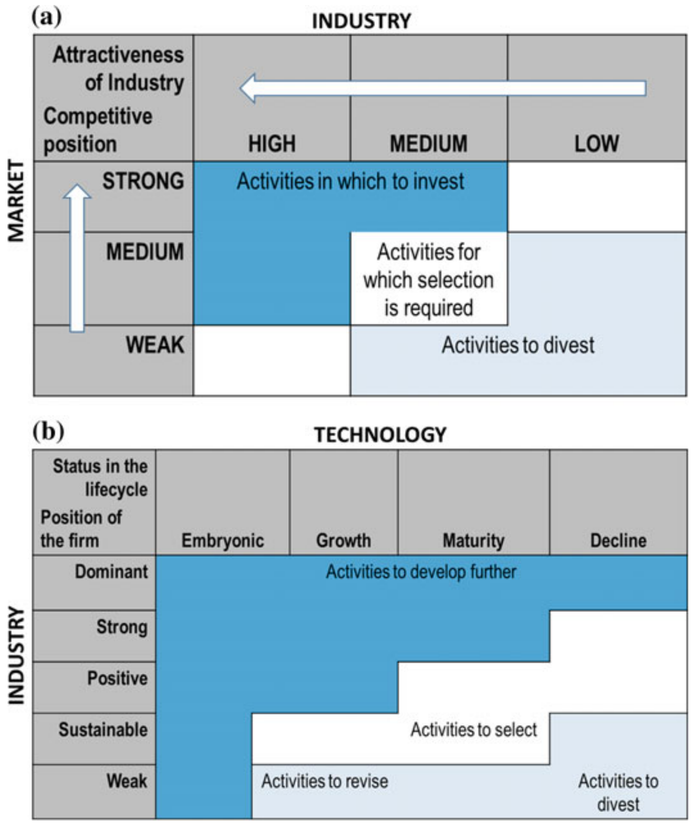


**Fig. 6.3** The A.D. Little (**a**) and GE/McKinsey (**b**) product portfolio matrices

## 6.3 Innovation Strategy and the Theory of Competitive Advantage

The theory of competitive advantage is a well-known approach to strategy formulation, proposed by Michael Porter* (1979). We will at first provide a very short explanation of this theory, and then relate it to innovation strategy.

### *6.3.1 Competitive Advantage, the Five Forces and Generic Strategies*

According to Porter (1985), firms must not be considered as isolated entities, as in the previous product portfolio approach. The firm, instead, must be viewed as part of a value chain that links it to upstream suppliers and downstream customers, and as part of a competitive context made of current and prospective rival firms. Following Porter, the competitive environment can be studied from the perspective of industrial economics, and specifically following the so-called *SCP* (structure-conduct-performance) *paradigm** (Bain 1959). In very simple terms, this paradigm states that, given an industry structure, rationality in economic agents' behavior will determine the way with which firms operate and—in turn—that this behavior will determine their performance.

As a direct consequence of this perspective, a firm's main strategic competence will at first consist in spotting a potentially favorable industry and entering. Due to the determinism that is inherent to the SCP paradigm, it would be quite unlikely to earn money by operating in an industry in which profitability is structurally low. Secondly, the firm must structure its operations (i.e., it must invest in tangible or intangible assets and organize itself) to create as much economic value as possible.[4] Finally, it must maneuver in the environment to retain the value created, without having to share it with other actors. When a firm is able to do so better than its competitors, it will record higher contribution margins and profits, and we will say that it enjoys *competitive advantage* with respect to rival firms.[5] If the firm is able to

[4]By economic value we intend the gap between the price that customers are willing to pay for the firms' products and the costs required to produce them.

[5]Following Grahovac and Miller (2009), competitive advantage is in its stricter sense connected to the above-normal *contribution margins* (i.e., the difference between unit price and variable cost) the firm earns in its product market. This is a necessary but not a sufficient condition for profitability, since significant profits will arise only if the firm does not spend too much money in *factor markets*, when acquiring or developing its assets. These assets may in fact be expensive either because they might be inherently costly, or because whoever sold them to the firm (e.g., an equipment maker, or an employee negotiating her salary) might be able to foresee their economic potential and raise prices accordingly.

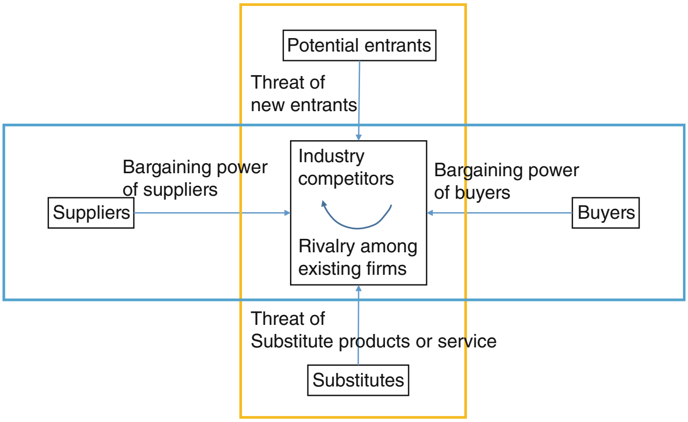


**Fig. 6.4** Porter's Five Forces

avoid imitation by competitors[6] and keep this lead over time, competitive advantage will be said to be *sustainable*. To systematize this game of value creation and retention, Porter identified the following *Five Forces* that act on the firm and attempt to reduce its competitive advantage (Fig. 6.4).

- **Competitors** exert a first powerful force because they constantly try to gain market share by reducing prices, improving their product offering, and imitating the firm. This is associated to the degree of existing *rivalry* between firms, which has to do with the number of competitors, their similarity, and the existence of exit barriers forcing rival firms to fight for their position and survival.
- **Suppliers** can observe the profitability of their customer firms and try to share some of this economic value added by increasing prices. The intensity of this force has to do with vertical integration choices and with the bargaining power of the parties involved.
- **Customers** too can observe the profitability of their suppliers and, especially if competition and bargaining power allows it, they will try to reduce the price for the goods they buy.
- **New entrants** will observe the industry and, if they consider profitability high enough to overcome existing *barriers to entry*, might decide to enter, therefore increasing competition.
- **Other industries** might provide products that are—to some extent—substitutes to the ones being produced by the focal industry. Therefore, they too exert a force that is similar to the one being applied by competitors.

[6]Always following Grahovac and Miller, imitation will be more likely if profitability is very high (i.e., if competitors see very attractive contribution margins and/or believe the cost of observing and replicating the firm's assets to be comparatively low).

Finally, Porter suggested that competitive advantage can be achieved by following one of four main *generic strategies*, summarized in the following Table 6.1. In Porter's view, a firm must make a clear choice among these strategies. Trying to pursue more than one of them at the same time would lead the firm into being stuck in an awkward position and not really being effective in any of them.

**Table 6.1** Porter's generic strategies

| Strategy | Industry-wide cost leadership | Cost leadership in different market segments | Differentiation | Focused differentiation |
|---|---|---|---|---|
| Description | Being the lowest-cost producer in the industry | Being able to serve many horizontally differentiated market segments at a low cost | Being able to serve many vertically differentiated segments and maximizing margins gained in each | Specializing to serve a single customer segment or niche |
| How can it be achieved in the product | Reducing direct cost<br>Exploiting economies of scale by spreading R&D investment over a large volume | Being able to design products that are "just enough" for the needs of each segment<br>Exploiting economies of scope and spreading the same R&D investment over products in different segments | Being able to design products that maximize customer utility at each segment, at the lowest cost possible<br>Exploiting economies of scope by spreading the same R&D investment over products in different segments | Focusing design effort so that customers in the segment perceive the firm's offering to be the best concerning quality and cost |
| How can it be achieved in the process | Exploiting economies of scale by spreading production investment over a large volume<br>Exploiting learning economies | Developing a low-cost process that is "fine-tuned" to segment needs<br>Exploiting economies of scope and spreading production investment over products in different segments | Exploiting economies of scope and flexibility | Developing "fine-tuned" process that exactly meets the required performance, at the lowest cost possible |

### *6.3.2 Competitive Advantage and Innovation Strategy*

The competitive advantage approach goes quite deep into analyzing and defining firms' strategic behavior, and the connection with innovation strategy is strong, even though it may not be so obvious.

The first point of contact has to do with the concept of "entry", which is made up of an initial decision, followed by investment in assets and the organization of these same assets. Innovation is often relevant to this concept, since the firm may have to change its products or processes to successfully address the new market. For instance, a firm selling in a new geographic region may have to adapt its offering to local needs. Similarly, a firm may have to develop new products in order to make them attractive to a particular market segment.

The second point of contact between Porter's framework and innovation strategy is related to the role that innovation plays in determining the intensity of the Five Forces and the way these same forces determine the degree of *appropriability** of the rents deriving from the innovation (Cohen and Walsh 2001; Teece 2000; Teece and Pisano 1998; Levin et al. 1987).

If a firm is actively innovating products and processes, the forces being exerted by its competitors, suppliers, and customers will be abated. Especially if innovations are based on specific and scarce resources, tacit knowledge and unobservable routines, competitors may find it hard to imitate the firm and match the quality of its offering and its prices. Other factors that may influence appropriability of above-normal returns are legal protection (see the later section in this chapter), lock-in effects, and rapidity. Suppliers who are not directly involved in developing these innovations will not have much bargaining power, since the focal firm may easily switch to other suppliers, or simply threaten to do so. On the other side, customers, unable to find comparable offerings at other firms, will not be successful when asking for lower prices. Conversely, a firm that is not innovating at all, that is simply incorporating innovations proposed its suppliers, or whose innovations are characterized by weak appropriability, will be subject to a strong force coming from competitors (who can obviously use the same suppliers) and from the suppliers themselves.

When looking at the force coming from potential entrants, innovation can play an ambiguous role. A long stream of investment in incremental innovation, typical of the mature stage of an s-curve, can determine a strong barrier to entry, since it would be difficult for any entrant to build competencies comparable to incumbents' and reach the same level of technological proficiency. Conversely, radical innovation often destroys barriers to entry. In fact, radical innovations often go in the direction of providing technical means that make entry cheap and easy for about any player.[7] Moreover, radical innovation tends to occur during technological

[7]For instance, cloud computing dramatically lowered entry barriers in the Internet industry, since it allowed any startup to set up a highly-scalable business, without having to invest in equipment, but simply paying for the capacity used.

revolutions, when new technologies—or technologies that were originally alien to the industry—become relevant. When this occurs, the way is paved for firms that happen to have the newly required competencies and wish to enter.[8] Finally, innovation also changes the degree with which products can be substitutes to one another, and therefore influences the force applied by other industries.[9]

A third point of contact between innovation strategy and Porter's approach is related to the role played by innovation strategy in each of the four generic strategies outlined in Table 6.1. Specifically, the strategic role of R&D and innovation effort can be related to both its outputs and to its cost. Concerning output, innovative activity can lead to improved products and processes that are well suited to support the generic strategy that the firm intends to follow. For instance, a firm pursuing a cost leadership strategy may benefit by continuously innovating its production processes in search of greater efficiency. Conversely, a carmaker that wants to focus on sports cars will be likely to benefit if it directs its innovation strategy to enhancing the performance that customers in that particular segment are likely to value the most. In many industries, the cost a company incurs in when working on research, development, and industrialization of its new products is quite significant.[10] A company may therefore try to improve profitability by sharing development costs over the highest production volume possible. This can be done by pursuing either economies of scale or economies of scope. In the former case, the *same* product may be offered to a wider audience, for instance by operating on multiple geographic markets. In the latter case, the same R&D investment may be shared across a number of *similar* products, targeted to different market segments. This latter option leads to the concept of platform product development, that will be analyzed further in Chap. 9 and then, more extensively, in Chap. 14.

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[8]For example, the changeover that led from analogue to digital photography allowed the successful entry of firms who operated in consumer electronics and had the right competencies in technology and in the related business model.

[9]The air transport and railway transport industries were traditionally separate from one another, with the former representing the fast and expensive way to move between two locations and the latter the cheaper and slower one. The roughly simultaneous emergence of low-cost carriers (a business model innovation) and of high-speed trains (a process innovation from the perspective of railway companies), have made the two industries close competitors for short-range trips. In many cases, air transport can be cheaper than train transport and even slower, if one takes into account the trip from cities to airports and back, together with check-in, security clearance, and boarding times.

[10]To provide some reference figures, the development and industrialization of a motor car can cost approximately 1 B€. In the case of a commercial airplane, the investment can be in the order of 15 B€. When divided by expected production runs, one can notice that the R&D cost per unit sold often is of the same order of magnitude as contribution margins. So, if a firm is able to spread the same investment over a higher production run, profitability can be substantially increased. Conversely, if demand falls short of forecasts, profitability will be destroyed.

## 6.4 Intellectual Property Rights and Competitive Advantage

When a firm bases at least part of its competitive advantage on technology, it quickly realizes that the sustainability of this advantage is critical, since competitors will readily try to imitate its products and processes. Not having an adequate defense strategy against imitation would represent a big loss to the firm. In fact, competitors would not only be able to compete head-on with it, but would do so with the advantage of not having to recoup the investment that the firm has made when developing new competencies and new technology.

The management of a firms' *intellectual property* (IP) therefore is a key element of innovation strategy. This section will attempt to very briefly outline the main aspects and current challenges in this vast and quickly evolving field.

In general, Intellectual Property has to do with patents, copyright, and trademarks. The former are associated to technical inventions and are therefore central to technological innovation. Copyright is associated to the various forms of artistic expression, with the notable inclusion of a strongly technical subject such as software. Finally, trademarks are associated to corporate or product identity and to marketing. The focus of the following discussion will be on patents.

### 6.4.1 *Patents*

The mainstream approach with which a firm that has developed a new invention can try to avoid imitation is to use a legal mechanism called a *patent*. A patent is a legal document with which a government agency called a *patent office*, having successfully examined a *patent application* describing the invention, grants monopolistic rights to the *applicant*[11] to produce and sell the invention for a predetermined period of time (usually 20 years). The patent application contains a detailed account of relevant *prior art*, to highlight the novelty of the invention, a *technical description* of the invention, and a set of *claims*. The claims are the heart of the patent, since they represent the legal boundaries of what exactly will be covered by monopolistic rights, if the patent is eventually granted. Therefore, elements that are contained in approved claims will be subject to monopoly, while elements that are not can be freely imitated by competitors.[12]

[11]For the sake of simplicity, we will only talk about applicants, though patent law makes a distinction between *inventors* (who are always natural persons) and *applicants* (which may either be natural persons, or a legal entity, such as inventors' employers).

[12]One can draw an analogy between intellectual property and land, with patents being the equivalent of property deeds, and the claims the equivalent of the topographic description of the land. The analogy between intellectual property and land is not perfect and is often criticized by scholars, but is quite useful to allow a quick understanding of the subject.

With some variations across countries, patent applications are confidential until the patent is awarded. At this point, the patent is published, so that competitors may be made aware of what they can and what they cannot legally produce and sell. Since the patent is published, competitors are also made aware of the new state of the art and may try to improve the invention or circumvent it (i.e., they may try to achieve similar or better outcomes in a way that is “sufficiently different” from what is spelt out in the claims), eventually achieving a new invention and applying for a new patent.

For a patent to be awarded by the Patent Office, the invention must satisfy a set of criteria, which can slightly vary from country to country. The most common criteria include the following:

- *Patentability of subject matter*. Governments usually make an up-front decision of which subjects can and cannot be patented. For instance, while an inventor can patent a complex mechanical device, a scientist is not allowed to patent a law of nature he has discovered. As we will see in the next section, patentability of subject matter usually raises hot debates, especially for emerging fields of technology;
- *Novelty*. For a patent to be issued there must be an invention. Therefore, it is not possible to patent something that is already part of prior art. A patent will obviously not be awarded to an applicant if someone else has already commercialized it, or described it in a paper, in a previous patent or in some other form of public demonstration. What is less evident is that the patent cannot be awarded even if the same applicant or inventor has made it public through any means.[13] Therefore, successful patenting requires keeping a high degree of confidentiality during the development of the invention. When an inventor must interact with another party before filing a patent application, she will always ask to sign a *Non-Disclosure Agreement*. This legal document not only binds the other party to confidentiality, but constitutes evidence that the nature of this knowledge exchange is not public and may not be considered as an impediment for a future patenting activity;
- *Non-obviousness*. To be patented, the invention must not only be new, but must represent a sufficiently marked improvement over prior art. The general principle is that the technical solution must not be obvious “to a person skilled in the art”.[14] This requirement avoids the patenting of trivial inventions or minor improvements that routinely occur in any product design and development project;

[13] Some countries, such as the United States, grant a *grace period* allowing an applicant to file a patent application within a given interval (12 months) after a public disclosure event.

[14] In European patent law, this criterion is substituted by the concept of *inventive step*. This concept requires the patent application to identify a problem that is not adequately solved by prior art, that the invention allows to solve the problem, and that it does so by using means that are not obvious to a person skilled in the art.

- *Utility.* This principle varies across countries but is generally aimed at avoiding useless or fantastic inventions. The applicant must therefore demonstrate that the invention is useful to solve some kind of problem and that it can work in practice. In the European Union, the requirement is stronger and calls for the invention to be susceptible of industrial application.

From a more general perspective, one can wonder about the societal role of patents, a topic that often gives rise to strong debates. After all, governments usually dislike monopolies and even set up antitrust agencies to fight them. Why should governments therefore set up a patent office with the mandate of authorizing 20-year old monopolies?

The main explanation lies in the fact that—if patents did not exist—there would be no incentive for individuals and for firms to invest in technological development. In fact, it would not be rational to pursue any R&D effort knowing that, after having sustained the related costs and risks, competitors could simply copy the invention and take out the firm's competitive advantage, without even having to recover the investment. Besides the purely economic reason, one might also argue that allowing this kind of behavior would not be fair. A government granting a patent therefore allows the inventor to become a monopolist and "tax the citizens" as a reward for the investment made in developing the invention.[15] At least in principle, the patenting mechanism should be self-regulating with respect to the importance of the invention. An invention with little market appeal will be rewarded with meager monopoly profits, while a highly useful invention will have wide commercial success and lead to abundant profits. Moreover, a commercially attractive but technically marginal invention will attract competitors, who will readily improve or circumvent it. In such a case, the original 20-year monopoly would effectively be brought to an end in a short time. Conversely, a highly creative invention will last much longer before it is made obsolete, and the inventor will therefore benefit from a much longer effective monopoly.

Besides providing incentives to innovators, patenting also provides two additional benefits. First, if patents did not exist, the only weapon available to investors would be secrecy. This would be an inefficient way for society to pursue innovation, since it would force would-be imitators to "start from scratch" instead of allowing them to learn prior art by reading previous patents and then trying to improve them (i.e., "standing on other inventors' shoulders"). Finally, patenting creates a system of legally defined property rights that allows the commercial trade of intellectual property, which can lead to an efficient societal use of the outcome of

[15]The exact definition of the rights granted to patent assignees requires a careful balancing between the private interests of the inventor and of society at large, especially when dealing with sensitive matters like health care. One typical issue is the righteousness of allowing patent holders to sell drugs at monopoly prices, which may be prohibitively expensive for poor patients in developing countries. However, while it is reasonable to think of adapting the patent system to these cases, it would be quite questionable to scrap it altogether. It is in fact likely that, if patents did not exist, we would not have "new drugs for all", but simply "no drugs for anyone". For a deeper discussion on this topic, one can refer to Schacht and Thomas (2005) and Boldrin and Levine (2013).

inventive activity.[16] If the inventor does not feel able to personally exploit the monopolistic rights tied to the patent, she can sell or license the patent. When considering whether to finance a new venture, a bank or an equity investor will consider a patent-holder favorably, since the patent shows that the invention does not breach other inventors' rights (i.e., it enjoys what is called *freedom to operate*), and it grants monopolistic rights. This makes the new venture more likely to be profitable and—if something should go wrong—it provides the chance of selling the patent to recoup at least part of the investment.

## *6.4.2 A Strategy for Intellectual Property*

When an invention has been developed, a firm must define a strategy for managing this intellectual property and for sustaining the competitive advantage that might come out of it. This subsection will discuss both patenting and other possible approaches.

### 6.4.2.1 Patenting Decisions

The most obvious approach to manage intellectual property is to apply for a patent. If the patent is awarded, the patent-holder can use it in a number of ways. First of all, it can directly exploit its monopolistic rights by producing a product based on the patent, provided it has the organizational and financial resources that are needed to successfully develop, produce, distribute, and service the product. In many cases, the firm might lack these resources, or might consider that it will not be able to fully exploit the market potential of this invention. For instance, it might feel unable to develop products quickly enough, to come out with a wide enough range of products covering a number of market segments, or to expand internationally. In such cases, it might decide to transfer the monopolistic rights to another party by either selling the patent or by licensing it.

In the case of a sale, the firm completely ceases its involvement with the invention. In general, the uncertainty surrounding the commercial value of the invention will lead the buying firm—who will have to bear all future risks—to offer a limited amount of money. As a matter of fact, patent sales often occur in bulk,

[16] In general, a precondition for economic development is the existence of a legal framework defining property rights over assets (Claessens et al. 2003). In the case of real assets, such as land and buildings, such a legal framework allows economic development in traditional economies by providing an incentive for saving and investing, reducing the need to spend on security, and allowing trade and financial transactions. Coming back to the analogy between land and intellectual property, one can therefore consider a framework defining intellectual property as a necessary element of economic development in the contemporary knowledge economy.

when the transaction is associated to an entire patent portfolio or to the acquisition of a firm.

Instead of selling the patent, the firm may opt to *license* the monopolistic rights to a *licensee*, in exchange for *royalty* payments. Depending on the agreement reached, the license may be unlimited or bear limitations in time, geography, destination market, and sublicensing rights. The royalty fee is usually specified as a percentage on the revenues accruing from the sale of products based on the patent, so that risks are split between the two firms. The licensor may also cooperate with the licensee's product development activities to facilitate the *technology transfer* process, in which case additional payments may be required to cover the related effort. Finally, the firm may decide to do nothing and simply use the patent to prevent other firms from developing products based on the technology it has invented.

In many instances, the technology landscape can become so highly fragmented that commercial products can be developed only by having simultaneous rights to use the intellectual property owned by multiple firms. In these cases, and in order to simplify the management of IP and avoid costly lawsuits, firms may decide to *pool their patents* and *cross-license* their patent portfolios, thus giving each other a license to use their respective IP. In case of asymmetric patent portfolios, cross-licensing can be accompanied by transfer of payments to the firm with the largest or most significant portfolio. Hence, both to gain a stronger bargaining position in cross-licensing deals and to be well-positioned in case of lawsuits, firms have a strong incentive to build large patent portfolios, sometimes without too many regards concerning the actual value of each patent.

From a financial perspective, the value of a patent can be accounted for by considering the costs incurred to develop the technology. A better valuation can be made by estimating the net present value of future cash flows that might derive from its commercial exploitation. Building on this concept, an emerging area in IP management is associated to using intangible assets, such as patents, in corporate finance (Lev 2001). Patents may be appraised and used as collateral to secure loans from banks or enter commercial agreements with other parties. Similarly, patents and related royalty streams may be securitized,[17] thus allowing the innovating firm to quickly raise financial resources.

IP management is becoming a very complex field, requiring skills and competencies that go beyond the capabilities of most firms. Because of this, IP has spawned an industry with a number of intermediaries acting as advisors, brokers, appraisers, licensing and enforcement agents, etc.

Together with undeniable advantages, the choice of patenting an invention also has a number of drawbacks, which must be carefully considered before engaging in this process.

[17]Securitization of IP means generating and selling a financial instrument based on a given pool of IP assets. The buyer of the security pays the asset holder a given sum up front, in exchange for a stream of payments that depends on the revenues generated by the assets themselves (Cohen 2005).

First of all, patenting is quite expensive, especially to individuals and small firms. An initial cost comes from administrative fees due for filing the patent application and for renewing the validity of the patent over time (*maintenance fees*). An additional cost comes from hiring a good patent attorney, who will have to spend time and effort to write a strong patent application. In fact, the application must have carefully worded claims that might make it through the examination procedure and—most of all—hold up well in court, should someone challenge the validity of the patent and/or should the inventor decide to sue infringers. While it is possible for an individual to write a patent application personally, the risk of coming up with a badly written, weak and economically worthless patent is very high. Filing costs may escalate quite steeply in the case of complex inventions, in which a strong protection can be achieved not by filing a single patent, but a number of related ones, thus developing a *patent thicket*.

A second cost is related to the geographic coverage of the patent. Unfortunately, there is nothing like a worldwide patent, and inventors must rely on a system of national patents that cooperate with each other under the auspices of a United Nations agency called World Intellectual Property Organization (WIPO). Therefore, to gain effective protection and maximize the economic value of the invention, it is wise to obtain patent protection in a sufficient number of countries, starting from the ones in which the market for the invention might be larger.[18] This leads to a multiplication of expenses, especially considering that the economic weight of developed countries is shrinking, and that market potential will therefore be spread over a high number of countries.

A third cost is associated to the *enforcement* of the patent. A patent holder must spend considerable resources to observe the relevant industry and make sure that no imitator is infringing on her IP. This is relatively uncomplicated for simple products that can be easily reverse-engineered, but it can become prohibitively difficult for complex products, and especially for process inventions. If infringement is suspected, the patent holder must then start a legal procedure that can have uncertain outcomes, requires considerable time and implies significant costs to pay lawyers and expert witnesses.

Aside from its costs, patenting exposes inventors to a number of risks. Having to disclose the invention allows competitors to gain know-how and use it to improve the invention or circumvent it. Competitors may also notice that the commercial use of the invention requires the use of some other technology, and come up with one or

[18] In practical terms, worldwide coverage is obtained by using a procedure defined by the so-called Patent Cooperation Treaty (PCT). In a nutshell, within 12 months of the first filing in the initial country, the applicant has the opportunity to file a *PCT application* expressing interest in international extension of the patent. The PCT application is at first examined at international level and—if the response is positive—the applicant can within 30 months move into the so-called *national phase*, in which she must decide in which countries the patent should be extended and start the related procedures.

more *blocking patents*, thus reducing its economic value. Finally, competitors may simply wait for the patent to expire and then legally start commercializing the product themselves.

#### 6.4.2.2 Alternatives to Patenting

Given the significant problems connected to patenting, a firm may keep the intellectual property as a *trade secret*. This strategy would obviously not make sense in the case of products that are easy to reverse-engineer. Conversely, it can be the best solution in the case of process inventions, and it is commonly followed in continuous process industries such as food, basic materials, etc. When deciding to keep an invention as a trade secret, the firm avoids disclosure and the related risks of circumvention. Competitive advantage will last as long as the secret is kept or until a competitor independently comes up with the same—or a similar—technology, and this may well occur beyond the 20-year duration that a patent would have granted. At the same time, keeping the secret involves significant costs in security management and in ensuring the loyalty of the employees who share critical know-how. Should a competitor manage to illegitimately gain access to this knowledge and copy the invention, it may be difficult to bring forth a successful lawsuit. In most jurisdictions, it will in fact be up to the original inventor to prove that the imitator has illegally accessed its own proprietary knowledge.

In some cases, and especially in the case of small firms in fast-moving industries, inventors often decide not to patent, but to simply rely on the speed with which they think they will be able to continuously improve the technology. By following this option, imitators are legally free to imitate the inventor's products, but the inventor expects them to take longer than he needs to improve the technology further. This strategy brings forward two risks. The first one is associated to making a wrong estimate on the speeds of development and imitation. The second risk is that competitors may attempt to patent the technology they have imitated. Such a patent would of course be invalid since—once commercialized—the original product constitutes prior art. However, the patent office might ignore this, especially if the inventor has gained a very small access to the market. In this case, the inventor might bring a lawsuit against the imitator and ask for the patent to be invalidated. To do so, she would have to produce evidence of the timing at which the original product had been disclosed to the public. This can be a costly and time-consuming act, and the inventor would not be able to gain any financial benefit, beyond regaining his freedom to operate. To avoid such a thorny situation, it is common for firms who do not wish to patent—but who want to avoid being "patented out of their own inventions"—to make an *invention disclosure*. In other terms, the firm publishes a description of the invention in such a way that the timing is officially recorded and that there might be no doubts about priority. Sometimes, specialized disclosure newsletters or bulletins are used to this purpose, which have the advantage of being regularly consulted by patent examiners when assessing prior art.

### 6.4.3 Emerging Issues in Intellectual Property Management

The previous discussion has hinted at the growing complexity of intellectual property management. This complexity has recently led to a debate on the adequacy of current rules and institutions. This debate is of direct interest to policymakers and also to practicing managers, who must constantly grapple with problems for which solutions do not appear to be perfectly defined.

#### 6.4.3.1 Patentability of Emerging Technology

One first issue is concerned with the patentability of inventions that are of growing importance in modern society. For instance, there is uncertainty on whether life forms, software, algorithms, and business methods should be patentable or not.

The debate on patentability of life forms deriving from genetic engineering techniques is highly specialized and is also laden with ethical aspects. This prevents us from discussing it in this short chapter section, and interested readers may refer to specialized literature (Knoppers 1999). Moving on to "soft" inventions (i.e., software, algorithms, and business methods), the debate is highly relevant to the services industry, which nowadays makes up a significant part of the economy in advanced countries. For firms operating in services, the availability of patenting as a tool for protecting inventions can have a significant impact on their competitive advantage and on the incentive they have to engage in research and development (Spulber 2011). At the same time, critics of patentability of "soft" inventions highlight the risk of granting protection to trivial or highly abstract innovations that might have nothing to do with technology. The debate is still ongoing, with a strong debate on the essence of technology in contemporary society, and with significantly different outcomes across jurisdictions. For instance, the United States are relatively open to patentability of these artifacts, and attention paid by its judicial system seems to be shifting from arguing about principles to the more pragmatic problem of avoiding the issuance of bad or weak patents. The European Union has instead taken a different stance and has in principle ruled out patentability of software, algorithms, and business methods. However, software can still be patented in the EU if it can be framed as a *computer-implementable invention** solving a technical—but not a business—problem.

#### 6.4.3.2 The Fragmentation of the Technological Landscape

Another important issue is connected to the growing complexity of intellectual property. In some industries, such as telecommunications, IP is becoming highly fragmented, with many narrow patents being assigned to different firms. This makes it very easy to inadvertently infringe other actors' IP, and creates situations in which a single denial to license could block other firms' activity, thus paving the way for costly judicial action, or *patent wars*. This fragmentation also creates opportunities for so-called Non-Performing Entities, or *patent trolls**, to buy patents in bulk and then opportunistically look for licensing revenues by threatening legal action against manufacturers who might be infringing on their IP. The legitimacy of this activity is often questioned, since patent trolls do not carry out R&D, do not have a real business interest in the commercial exploitation of the inventions, and do not represent the interests of inventors. However, courts find it hard to reject their cases, since legally acquired property rights are always valid, regardless of the rights-holders' belonging to the group that the law originally wished to encourage by creating the rights themselves.

A fragmented technological landscape leads to another perverse mechanism that can impact the credibility of the patent system. When companies file numerous patent applications for relatively narrow and potentially worthless inventions, a patent office can be overwhelmed by the workload. To solve this problem, it is not thinkable to discourage excessive patenting by increasing administrative fees, since this would be especially damaging to individual inventors and small firms. Another alternative would be to increase the staff of patent examiners, but the cost to taxpayers would be quite high, not counting that it would be difficult to recruit and train highly skilled professionals in bulk. So, if one does not want to delay the lead time with which patent applications are examined, which would leave applicants in an uncertain state for an unacceptably long time, there will be a temptation to examine patents less thoroughly (Shapiro 2004). Patent examiners know that only a minority of patents will actually lead to products and have any economic value. Of these, only a small portion will lead to litigation. Therefore, there is an implicit incentive to examine patent applications somewhat less thoroughly, and leave the final decision on their validity to the court, if it will eventually be challenged. While this effect can be rational from an administrative perspective, it has the fault of leaving patent holders in a state of uncertainty on the very existence of their IP rights and on their related value.

#### 6.4.3.3 Alternatives to Patenting

Now and again, the evident limitations of the patenting system has led critics to propose alternative approaches for dealing with IP and creating incentives to inventors. One of the possible approaches is *subsidization*. With patenting, private firms invest in R&D *ex-ante* and, in exchange, the government grants them the right to "tax citizens" with monopolistic rents *ex-post*. One could imagine a system in which the government raises an innovation tax *ex-ante* and funds companies' R&D under the requirement that the results be openly shared. Critics to this idea claim that the system would not work, since project selection and resource allocation would be performed quite badly by a government committee, compared to the market-based interaction between multiple corporate shareholders, managers, and customers. Moreover, the incentive to work hard for completing a government-funded project that simply covers costs would not be as strong as the one coming from the opportunity to gain a monopolistic status under private funding. However, there are cases in which market forces might not be able to select the projects that maximize social utility. For instance, pharmaceutical companies are often criticized for working on *lifestyle drugs* addressed to rich countries, and not dedicating enough effort to develop potentially life-saving medicines for emerging countries or for *orphan diseases**, where the financial rewards might be lower.

Another popular "alternative" approach to patenting is *Open Source*, which is currently extending from the domain of software to other fields, such as electronic hardware. The main concept behind Open Source is that inventors should allow others to freely use and add to their developments, since this can greatly increase the speed with which innovation evolves. If a wide community of technologists—instead of a single company—works on the same problem and collectively generates a standardized solution, both technical performance and diffusion may be accelerated (Raymond 2001). Of course, if one does away with monopolistic rights associated to patenting, some kind of incentive for performing R&D must be restored somehow (Lerner and Tirole 2005). According to proponents of Open Source, this individual incentive might be relatively small, since R&D effort is shared by a wide community. Moreover, even though they cannot use the technology as monopolists, developers will be able to profit from their effort by selling related services, such as customization, training, and complementary goods. The incentive mechanism works on the principle that the greater an individual's contribution to the technology, the greater the specific knowledge gained and the public reputation, and the more valuable these services will be on the market.

Despite some initial skepticism due to a somewhat strong ideological rhetoric, Open Source strategies have proved themselves quite successful in a number of fields. Most Internet companies use Open Source as the underlying technology, since their economic value comes from the services that they run, the way users are attracted, and the profitability of the business model. Furthermore, many established firms in the software industry have developed strategies that mix Open Source elements with proprietary software, to exploit the benefits coming from both models of IP management.

*Prizes and competitions* are another possible approach that may stimulate technological development. During the early twentieth century, significant advances in the development of motor cars and airplanes came from contests and from attempts to breach previous performance records. Even today, many advances in the field of motor cars derive from the efforts spent in Formula 1 car racing. This approach might not on its own create sufficient incentives for significant R&D investment and technological development. Moreover, being based on a tournament-like mechanism, in which multiple participants have to invest and only one wins the prize, the magnitude of the investment will tend to be quite small. However, despite these drawbacks, prizes can be considered a useful complement to other means for providing incentives to innovation.

## 6.5 Shaping Strategies

When attempting radical and potentially disruptive innovation, companies may profit from taking bold strategic moves, trying to generate and become leaders in new markets and industries, rather than fighting for market share in existing ones. This idea is sometimes termed *Blue Ocean Strategy**, from Kim and Mauborgne's (2005) popular book. The rationale is that, by challenging incumbents on their home turf, entrants are likely to be at a strong disadvantage. The old technology may have generated lock-in, while incumbents enjoy strong competitive advantage thanks to complementary assets and reputation. Even more, the way customers conceive products and their relationships with producers might be well-suited to the old technology, but might not fit well with the new one. Therefore, entrants may enjoy greater likelihood of success if they propose a "new game", in which they have a clear technological advantage, knowing that incumbents will find difficult to adapt to it, instead of playing the old one.[19] The same argument can apply to firms that are currently operating in highly competitive industries (or "Red Oceans"), who should carefully consider whether to continue competing in the traditional way, or propose radically innovative strategies. This school of thought is a clear departure from Porter's "structuralist" model, based on pre-existing industries and markets, and has been defined "reconstructionist", since it aims at their redefinition (Kim and Mauborgne 2009).

When following a "Blue Ocean" approach, strategy must be based around a set of key elements. The first is the concept of *Value Innovation**, which requires aligning the economic value of the firm's offering (which broadly includes products, services, and channels) to customer segments, defining target prices that might make the offering attractive to customers and profitable for the firm. Shaping strategies are generally not limited to product innovations, but are usually extended to the entire business model. So, firms should not simply think of designing new products, but design a business around an aggregate of available technology and unmet user needs. Given the relevance of business model innovation, the following Chap. 7 will be dedicated to examining this topic in greater depth.

Authors such as Martin (2009) have advocated making use of creativity instead of simple analytical skills, when dealing with strategy. To this purpose, he has suggested using *Design Thinking** (Brown 2009; Cross 2011), which is a general problem-solving approach that has emerged from the design community and from its growing involvement with problems ranging from the design of complex systems to policy-making.

[19] As an example, one can observe the introduction of the Wii by Nintendo in 2006. Nintendo aimed at broadening the user base in the games-console industry by making games easier, natural, and fun to play. This went against the prevailing trend followed by the industry, which focused on computing power and visual performance, to cater to the specific needs of a "core" of passionate game players.


**Fig. 6.5** The foundational elements common to "shaping strategies" (after Hagel et al. 2008)

Other elements typical of shaping strategies include dropping Porter's dichotomy between low cost and differentiation strategies, and trying to pursue both of them at the same time, while striving to maximize speed of adoption of the innovation.

Following Hagel et al. (2008), shaping strategies usually start (as in Fig. 6.5) with the definition of a "vision" for value creation. To implement the vision, the firm must decide which elements it wants to be responsible for, and which should instead come from users, customers, stakeholders, and complementors. At the core of shaping strategies is the realization that it would be very difficult for a single firm to provide all the necessary elements on its own. Furthermore, it can be much more efficient to partner with existing actors and their established competencies, rather than trying to replicate them from scratch and maybe even competing against them.

One key enabler of shaping strategies, which is quite typical of Internet companies such as online marketplaces and social networks, consists in the development of "platforms" that may easily create and aggregate stakeholders and support the rapid expansion of the firm.

Thanks to the platform and to the actors and resources that have been attracted to it, firms can devise strategies to quickly grow and scale their activity up, both to guarantee returns on the investment made, and to achieve critical mass before any competitor does.

## 6.6 Innovation and the Resource-Based View

### *6.6.1 The Basics of the Resource-Based View in Corporate Strategy*

The approach to strategic management that is closest to innovation management probably is the so-called Resource-Based View (or RBV in short). From a theoretical perspective, the RBV is based on the same "evolutionary" theory of the firm we introduced in Chap. 2. The firm and its evolution are investigated by observing its inside, rather than its external behavior. Moreover, the firm and its organization are defined as a collection of assets that operate together thanks to bundles of routines, engaged in an endless game of path-dependent adaptation to an unstable environment. Therefore, while Porter's approach places rational decisions taken by managers at the center of strategy, the RBV considers the differences between firms and managers' ability to determine and exploit them as the main source of competitive advantage.

In the RBV jargon, routines that involve resources are termed *organizational competencies*. Among the many competencies that any firm possesses, a subset of them will have the potential of leading to strategic differences and creating competitive advantage. These can be termed *core competencies** (Prahalad and Hamel 1990). Consequently, according to the RBV, strategic decision-making consists in understanding which competencies are core, ensuring their continuous growth, together with that of the underlying resources, and then using them to enter markets in which above-normal profits may be achieved. In RBV terminology, a *capability** is a competence whose strategic value has been understood and is therefore used for strategy-setting. Finally, *dynamic capabilities** are higher-level competencies that a company uses to adapt, develop, and re-configure the existing portfolio of resources and competencies.

The RBV leads to the idea of managing strategy through core competencies (Hagel and Singer 1999). This approach posits that—instead of recognizing attractive markets and then structuring itself internally to serve them—the firm must recognize its core competencies and then find markets in which they may profitably be exploited. More specifically, core competencies can generally be recognized as a company-specific *blending* of generic competencies. If one considers technological core competencies, generic competencies would be represented by established technological domains, such as the various fields of engineering. The core competence would therefore come from a company-specific *technological fusion* of these fields, so that one firm may specialize in "optics and electronics" and another one in "mass producing products in which functional materials are applied to substrates".

Having acknowledged the core competence of the firm, managers can think of entering industries, serving markets, and developing products that might allow at that particular time the most profitable exploitation of these competencies, and exiting when appropriate. The firm will witness a continuous strengthening of its core competencies, due to the experience gained in many different fields, and will progressively enter and exit industries, depending on their coherence with core competencies, attractiveness, and stage of maturity.[20] Upon entry in a given

[20] A "core competency" must not to be confused with the "core products" offered by the firm. On the contrary, firms that define their strategy around core competencies tend to shift quite readily from mature products and markets to emerging ones, in which they feel such competencies might lead to competitive advantage. Not many firms are close followers of this strategic management approach. Well-known examples are Canon ("blending optics and electronics") and Corning ("amorphous materials technology", such as glass and ceramics). Both of these companies have progressively entered and exited industries, depending on the degree with which their core competencies were felt to be relevant. If one broadens the concept of competency to the "capability

industry, the firm will have to develop additional *integrative competencies* that are specific to the development of products in that particular field and *market competencies* that are specific to interacting with that market.

This process of entry and exit leads to diversification in a way that may superficially resemble the one followed by firms using the product portfolio approach. However, while the latters' entry and exit decisions are fundamentally based on financial considerations, the former will use coherence with core competencies as the main criterion. When the firm is not sure about this coherence, or when it feels that the integrative and market competencies that must be developed to support entry might lead it too far away from its core, it will probably avoid this decision, even if the market is financially attractive. It might therefore look for alternative strategies, such as technology licensing or vertical disintegration (i.e., selling key components), to profit from its competencies but without defocusing from them.[21]

### 6.6.2 Bridging the Core Competencies and Competitive Advantage Approaches

In many environments, and especially when competition if very intense and industry dynamics are very fast, neither the resource-based nor Porter's competitive advantage approaches are able to adequately support strategic management. The former tends to look at strategy from a rather long-term perspective, in which firms remain faithful to their core competencies and rather gradually shift their attention from one industry to another one. The latter too tends to have a long-term perspective, since it hypothesizes that competitive advantage can be sustained over time. So, firms will obviously tend to remain grounded in the industries where—sometimes after significant investment and fighting—they have become able to extract above-normal returns.

In a fast-moving environment, both approaches can fail to appropriately define a proactive way for defining the firm's future direction. Managing in a turbulent environment requires a continuous process of maneuvering, learning, and discussing with downstream markets and with providers of production factors, including technology. Some authors have termed this perspective as *theory of temporary advantage*

(Footnote 20 continued)

to serve a market", one can also consider firms such as Sony ("electronics for entertainment", which is the intersection between a market and a technology) and IBM ("technology for supporting business activities"). By observing the history of these firms, one can notice that these companies tend to have a long lifetime and pass nearly unscathed through the business cycles and the s-curves of the products they produce.

[21]For instance, in the '90s, Canon licensed its technology for laser printers and digital photocopiers to competitors, such as Xerox and HP, possibly giving up the possibility of becoming a near-monopolist player in that market.

(D'Aveni 1994; D'Aveni et al. 2010). They stress the idea that competitive advantage is seldom sustainable, and it is more appropriate to depict it as a prolonged sequence of temporary advantages. In such a context, the firm should not only think about defending its current competitive advantage, but also constantly look at how to establish its next one. The problem is by no means trivial, since the underlying decisions and trade-offs are quite difficult to frame and implement.

One first issue is related to allowing the cannibalization of a currently profitable business activity by a future one, which might be the foundation of the next temporary advantage. In general terms, it is usually quite obvious that the switch will have to be made at some point in time, but the crucial point is to understand when.[22] An early switch might determine first-mover advantage in the new paradigm, but also limit funding from the prematurely interrupted old one. Moreover, a fast mover risks entering an s-curve which might take years before it goes through the incubation phase and provides adequate returns.

A second issue is associated with path dependency and relatedness. The firm will have a strong competitive position if it tackles technologies and markets that are somewhat close to its current ones. However, a trade-off often arises if—by moving a little bit further away from them—it might address a field with larger business potential, albeit accepting to have a weaker competitive advantage.

A third problem has to do with the possibility that, in a rapidly changing environment, uncertainty may be so high that the firm becomes unable to conceive any strategy at all, regardless of the internal inertia with which it would be able to execute it. This kind of situation leads to a trade-off between the risk of not doing anything, thus missing out a possible trend, and of making costly and aimless moves before the time is ripe to take any clear action.

To frame the strategic management process within such a context, one can consider that a firm's core competencies will not be cast in stone. Competencies will evolve in time, along with the corresponding sequence of market entry and exit decisions. Following Helfat and Raubitschek (2000), this mechanism can be represented as in Fig. 6.6.

The model separates the firm in three elements. The first is the "knowledge system", representing the firm's portfolio of competencies, as given by its resources and routines. The second element can be termed the "activity system" and represents the aggregate portfolio of product and market development projects that describes the firm's activities in exploiting its competencies. This project portfolio can be viewed as the core element of the firm's business plan. The third element is the "learning system", which feeds back into the knowledge system and is concerned with updating the firm's competencies. Learning can occur in two ways. One is incremental and is due to the continuous use of core competencies in different industries. This implies substantial *experiential learning* (or learning-by-doing) and

[22] For instance, in 2011 Netflix had a very successful business in DVD rental, based on postal delivery, with which it has disrupted the traditional outlet-based business model. However, it had to bravely start promoting video-on-demand streaming, with a de facto cannibalization of its original rental model.

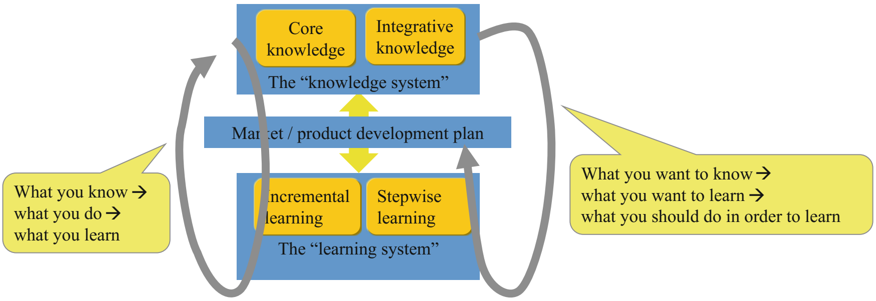


**Fig. 6.6** The evolution of corporate competencies

knowledge *spillovers*, when results that emerge from the work done in one industry turn out to be valuable in another one. A second mechanism is the *stepwise learning* that occurs when the firm wishes to make radical changes to its knowledge base. Stepwise learning generally happens when the technological and/or market environment is about to undergo significant modifications and the company want to be ready for, or react quickly to, this change.[23]

Based on this representation, it is possible to conceive the formulation of innovation strategy according to two main avenues. One can be viewed as a somewhat passive *competence exploitation* path, in which the firm defines a portfolio of product and market development projects, based on the competencies it possesses. By executing this plan, and thanks to incremental learning and spillovers, the firm will find itself with an updated knowledge base that will eventually become the basis for a new plan.

A second path consists in a proactive *exploration* of new fields, in which the firm focuses on the competencies it feels will be needed in the future. The firm may do so by both enacting stepwise learning activities, without an immediate impact on the product and market development plan, and/or by purposely deciding to work on products and in markets for which it currently lacks competencies, with the very objective of developing them. By following this path, the formulation of an innovation strategy consists in defining a desired portfolio of competencies and a plan for developing them.

The two paths are complementary and not necessarily alternative to one another, since a firm may follow both exploitation and exploration strategies at the same time. Though in different ways, both paths operate on the two "levers" of formulating and planning two portfolios: a portfolio of competencies and a portfolio of product and market development projects. We can consider these two portfolios and their reciprocal interactions to be at the heart of innovation strategy, and Chaps. 8 and 9 will deal with them in depth.

[23]As an example, one can think of Kodak in the '80s. By envisioning that digitalization might revolutionize the field of photography and make film obsolete, the firm decided to invest significant resources in the development of the new technology.

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# Chapter 7
# Business Model Innovation

This chapter focuses on the emerging topic of business model innovation. The concept has already been mentioned in the previous chapters, and specifically in Chap. 1, during a preliminary discussion on different types of innovations, and then in Chap. 6, when introducing the concept of "Blue Ocean" strategy. Nevertheless, given its growing relevance in the field of innovation strategy, it is appropriate to dedicate a separate chapter to the topic. The subject will be discussed at first by providing some basic information and definitions, and then by exploring in depth two approaches that can be practically used to analyze and design business models.

## 7.1 What Is a Business Model

The concept of "business model" is relatively recent, since the term came in use only at the beginning of the twenty first century, when Internet companies started to emerge (Mahadevan 2000). For these firms, it was quite apparent that their activity differed markedly from the "traditional" operational model of buying, transforming and selling goods or services, and on the financial model of profiting from the difference between value of sales and the cost of goods sold. Search engines, auction sites, social networks and music streaming companies provide services to—and generate their revenue from—multiple parties in ways that are often quite asymmetrical and difficult to understand.[1]

When researchers started giving a closer look at the phenomenon, it became apparent that business models and business model innovation mattered for firms operating in other industries as well. First of all, many firms were introducing business model innovations that were bringing disruptive change to their respective

[1]For instance, a firm like Google may provide a free Internet search service to users, but make substantial profit by selling highly targeted advertising services to other firms.



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_7

industries. As a typical example, one can think of low-cost airlines, which represented a significant innovation in transportation, though the major change they introduced was clearly associated to the business model and not to the technical content of flight. Moreover, it became recognized (Chesbrough 2010) that business models represent the "format" with which firms can bring technological innovations to the market, and are therefore key to determining success and failure of the same innovations.[2]

Given the importance of business models and of business model innovation, researchers started working on precise definitions (Lee 2001; Shafer et al. 2005), on methods for supporting their study and on the relationships between business models and strategy (Magretta 2002).

As highlighted by Teece (2010), a business model represents a "*conceptual, rather than financial, model of a business*" and is therefore aimed at representing the constituent elements of a business and their coherence, rather than its profitability.

With some adaptation from Shafer et al. (2005), the key elements of a business model are represented in Fig. 7.1. These elements cover the main strategic choices that define a business, the resources which enable the firm to create value, the positioning of the firm in its value network, and a high-level definition of cost and revenue structures. At the same time, the elements in the business model cover both sides of supply (i.e., what is being offered and how it is going to be produced—by the firm and by its suppliers and partners) and demand (i.e., who is the customer and how it can be reached).

Once a business model has been developed, it is possible to "put flesh on the bones" and use it to generate strategies, business plans, profit and loss and financial projections. Conversely, strategies and business plans cannot really be articulated if not by referring to an underlying business model. Therefore, a firm's business model can be viewed as a more generic concept than its business strategy and as a precursor to it. At the same time, the former provides a high-level description of "what" the firm will do, but stops short of the latter's aim of stating how this can be effectively reached.

Literature has come up with a few approaches for representing business models. The main difference lies in the focus, which can be on an individual firm or on a complete ecosystem. Two well-known corresponding approaches are discussed in the next two sections.

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[2]This is by no means a recent phenomenon. For example, Thomas Edison realized that an isolated firm selling incandescent light bulbs would not be sustainable in a world where electricity was not commercialized. So, he developed a business model around the idea of selling complete electrical DC systems, including local power generation and lighting. Eventually, this business model lost against George Westinghouse's, which was based on AC systems that allowed remote generation of electricity and its long-distance transportation.

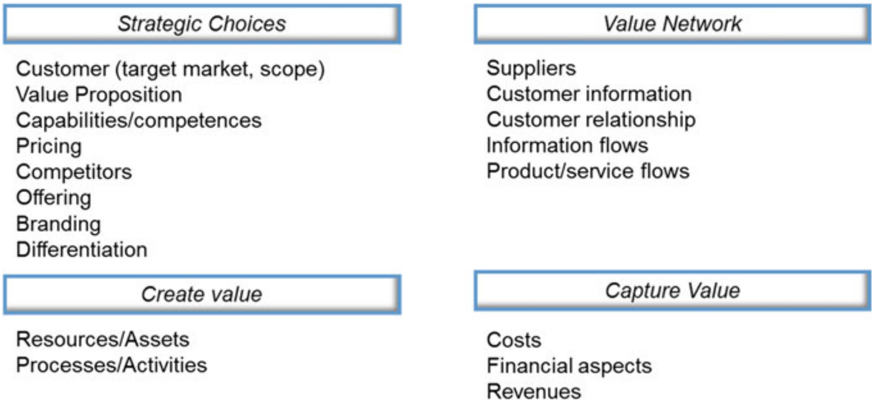


**Fig. 7.1** The main elements of a business model

## 7.2 Representing a Business Model from the Perspective of a Single Firm—The "Business Model Canvas"

The "Business Model Canvas"—or Canvas in short—(Osterwalder and Pigneur 2010) is a qualitative and informal tool for structuring business models. The Canvas came out of the authors' initial research on the constituent elements of business models and their ontology (Osterwalder 2004) and—being very simple and intuitive—it has become a de facto standard in both professional practice and academia. Its simplicity can be misleading, however, and its underlying concepts have to be correctly understood, if one wants to obtain sound results and not naïve ones. The following subsection will provide a description of the Canvas, while the following one will discuss its use.

### *7.2.1 The Main Elements of the Business Model Canvas*

At its core, and with reference to Fig. 7.1, the Canvas can be considered a concise, structured and static map of a subset of the key elements that make up the business model. However, it does not fully explicit the relationships between elements, nor does it represent the dynamic behavior of the firm's business model within its broader value system.

As shown in Fig. 7.2, the Canvas brings together four main areas of the business model: the product and the infrastructure (which cover the "offer" side of the

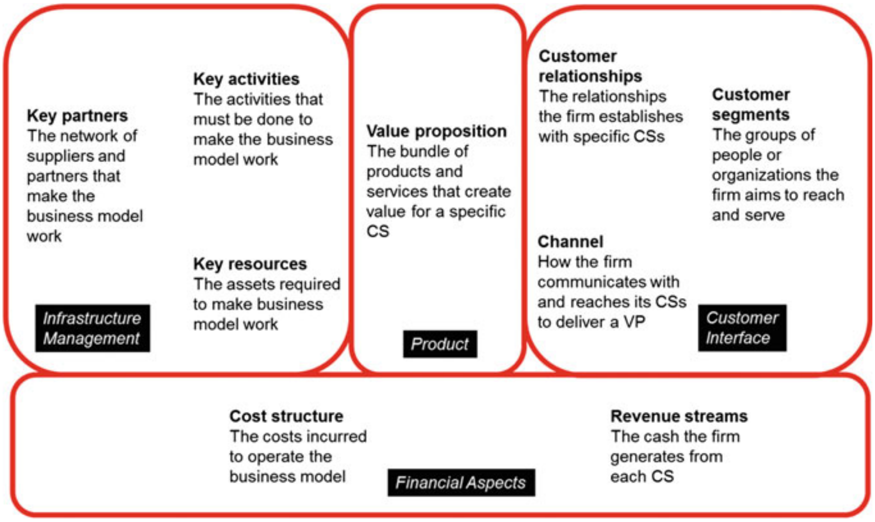


**Fig. 7.2** The business model Canvas

business model), the customer interface (which covers the "demand" side), and the associated financial aspects, based on the costs that characterize the side of "offer" and the revenues deriving from the side of "demand". In turn, these major areas are split in nine sections, which will be described in detail in the following. The order with which we start the discussion is meaningful for teaching purposes, and does not necessarily represent the order with which the Canvas should be tackled. As a matter of fact, it is quite likely that the compilation of a Canvas will undergo many iterations and back-and-forth jumps between sections, to achieve coherence.

#### 7.2.1.1 Customer Segments (CS)

We start from customers, who are key actors of the business model. In fact, a business is sustainable only if it offers some*thing* that is of value to some*one* who is willing to pay and cover the costs. The CS section of the canvas specifies the specific groupings of customers the firm intends to serve and provide value to (and, conversely, it implies which CSs will *not* be served). The definition of a CS should be narrow enough to provide a clear indication of the strategic choices that are being made (e.g., for a magazine, "readers" is too generic, while "teenage female readers" might be more adequate).

The CS section can list a number of different segments. Differences may be due to the variety of business relationships (e.g., readers and advertisers are both customers to a newspaper, but their nature is obviously not the same), needs (e.g., a family and a 30-year old single may not have the same needs when it comes to buying a laundry machine), willingness to pay (e.g., spectators willing to go to a premiere and people waiting for a later and cheaper show), and distribution channels (e.g., online shoppers vs. customers who prefer a traditional retailing experience).

Customer segments should not only be identified and described, but also quantitatively estimated. This information will be of great value when dealing with Revenue Streams later on.

Together with listing the CSs, it is important to generate a sufficiently deep understanding of customers' problems, needs and wants, so that they can later be associated to the firm's Value Propositions. Methods for eliciting and structuring customer needs will be amply discussed in Chap. 13 and—among them—the Empathy Map may prove to be particularly suitable.

#### 7.2.1.2 Value Propositions (VP)

At the heart of a business model and directly in face of customer segments is the concept of "value proposition", which describes the objects of the transactions that will be carried out with customers. A value proposition is not simply a product or a service being offered, but a descriptor of the value that underlies the product, makes it attractive and might give it some kind of competitive edge. It represents the way with which a customer need is met, or a problem is solved, in a way that is possibly better, faster, or cheaper than with competitors. In Osterwalder's terms, it is "*a bundle of benefits that a company offers customers*".[3]

The concept of value proposition is not an absolute, but is specific to the CSs that have been previously identified. A strong VP for one customer segment may be quite uninteresting to another segment. Therefore, providing a precise description of the value content of a VP in relation to its target CS is a key exercise in defining a business model. So, it is quite common to iterate back and forth a number of times to come up with a coherent set of VPs and CSs that map well into each other.

#### 7.2.1.3 Channels (C)

Once the team has defined CSs and the corresponding VPs, one can define the channels that allow the delivery of the latter to the former. Examples of channels can be physical (e.g., stores) versus virtual (e.g., websites), direct versus indirect. The role of channels is not simply to sell products and services, but to follow the customer over her purchasing process, from the initial raising of awareness and

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[3]For instance, while "a portable and Internet-connected electrocardiograph" is a good descriptor for a product, a better wording for its value proposition could be "a professional-grade ECG device supporting onsite telemedicine processes". The accent on "professional grade" can be useful, because it may set the device apart from other portable but lower-quality competitors, and the accent on the "telemedicine processes" shifts attention from a purely technical feature to the corresponding outcome, which can be of value to a potential customer segment.

evaluation of the products, and all the way to ensuring effective delivery and after-sales support.

Of course, Channels too must be matched with the specific VPs and CSs that make up the business model, and coherence must be sought for all of them.

#### 7.2.1.4 Customer Relationships (CR)

Customer relationships add another twist to creating a connection between VPs and CSs. While channels have to do with "institutional" or "physical" entities that relate the firm to the customer, Customer Relationships provide a description of the complete set of connections and bonds that engage the customer within these channels. For instance, the CR section may list elements such as personal assistance, automated services, user communities, and so on.

CRs cover the time of the initial purchasing decision (i.e., customer acquisition) and also the subsequent phases in which the firm deals with existing customers, for the purpose of retaining them and increasing sales.

When coming up with CRs, coherence must be ensured with VPs, CSs and Channels.

#### 7.2.1.5 Revenue Streams (RS)

The Revenue Streams section closes the portion of the Canvas that covers the demand side of the business model. Given the previously developed blocks, the firm can come up with a description of its revenue mix and a preliminary evaluation of its entity.

Revenues are of course closely related to VPs, since the value that is delivered to a CS determines—together with existing competition—each Customer Segment's willingness to pay. When defining the revenue stream that can be expected to accrue from each CS, the firm may also consider the possibility of allowing cross-subsidization between CSs.[4]

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[4]Subsidization means that one CS does not cover the costs it generates, but the overall business model stands on its feet because margins from some other CSs cover the difference. This typically happens in multiple-sided markets, in which one side subsidizes the other. For instance, the readers of newspapers are subsidized by advertisers. Subsidization also occurs in the case of vertically differentiated offerings. For instance, a passenger flying economy class with a cheap ticket is subsidized by business class passengers paying full fare. However, given the cost structure of an airline flight, which has high fixed costs and negligible variable costs, it's more profitable to carry an additional customer who does not fully cover his costs, rather than allowing a seat to be empty. Similarly, in "freemium" business models used in digital services, paying users are given a bundle of functions that make up a VP of higher value, and they subsidize the limited features being enjoyed by the non-paying-users.

When defining revenue streams, the firm will have to decide on its pricing structure. The list of alternatives is quite endless, but typical solutions are the following:

- Transactions versus recurring. In the case of transaction-based pricing, the customer is charged each time she uses the VP (e.g., you pay when you buy your newspaper). Conversely, in a recurring scheme, the customer is charged ex-ante for being granted the availability of the VP (e.g., you pay an annual subscription and get all the newspapers even if you won't read all of them). In some cases, pricing can be a mixture of the two (e.g., in many cities, bike sharing services charge a fixed subscription fee, plus a usage fee when bike rides exceed 30 min).
- Fixed versus subject to discounts. Prices can be fixed in a way that is independent from CSs, volume and product features. Conversely, the firm may engage in some form of price discrimination, offer volume discounts, and so on.
- Fixed versus proportional to value. This decision is relevant for products or services that are complements to other products or services. For instance, at-home delivery can be charged a flat fee of 2 $, or can be computed proportionally to the value of goods being delivered.
- Sale versus rental. In the former case, the customer gains ownership over the good, while in the latter it simply purchases the right to use it. A typical example is the selling versus the leasing of a car.
- Static versus dynamic pricing. In the former case, prices are fixed and do not change as a function of supply and demand at the time of consumption, and vice versa. For instance, taxi fares are subject to static pricing, while online limousine services (Uber is a well-known example) allow prices to vary according to supply and demand.

Choosing an appropriate pricing structure is not trivial, since it can have significant impact on customer behavior. For instance, a recurring fee can be off-putting at first but—once a customer has been acquired—it creates a much stronger incentive to consume than a per-transaction pricing scheme would. Dynamic pricing can be an efficient way to match supply and demand, but it can also be confusing and disturbing to unsophisticated customers and deter them from consumption.

Once a pricing structure has been defined, the firm can multiply the expected revenues per user by the size of each CS and come up with a preliminary estimation of its overall revenues and their composition by CS. This is not enough to assess the profitability of the business model, since this will also depend on costs. However, having a ballpark figure of the expected revenues can provide the decision-maker with a preliminary idea of the size of the business opportunity that is being developed.

#### 7.2.1.6 Key Activities (KA)

Once the VP and the demand side of the business model have been developed, the attention can now move toward the supply side, which is responsible of making the production of the VPs and their delivery to customers possible.

By analyzing the VP, C, CR sections of the business model, it is possible to come up with a list of activities that are needed to support them. When developing a Canvas, one will not waste time with activities that are generic and not particularly critical to the business model, but will focus on the ones whose execution is essential. Therefore, identifying KAs does not only serve the purpose of completing the business model canvas, but also allows managers to understand which parts of business operations will have to receive adequate attention both when formulating strategy and when executing it.

#### 7.2.1.7 Key Resources (KR)

The Key Activities that have been listed in the previous panel are made possible by Key Resources, whose identification is critical for understanding the business model and—later on—for making strategic decisions on their ownership. These resources can be physical (e.g., facilities, equipment, access to scarce raw materials, etc.), intangible (e.g., brands, patents, etc.), or human (e.g., skills and competencies). At this point, it is enough to list the resources, without actually defining how these same will be generated or used, either through direct investment or by accessing resources that are available on the market. In the KR section one can usually omit those resources that are not specifically crucial to the business model and are common to any company. For instance, any firm will need good banking services, but "access to credit" should be considered as a KR only for business models that require significant investment or working capital.

In the KR section one can include both long-term and current assets. The former are the fruit of investment, and the value they produce goes beyond the initial outlay (e.g., machinery, personnel's skills, etc.), while the latter assets are going to be quickly converted to VPs (e.g., stocks of raw materials, consumables, etc.).

#### 7.2.1.8 Key Partnerships (KP)

In the KP section of the Canvas, the firm makes vertical integration decisions with respect to the Key Resources it has previously listed. Specifically, the firm can decide whether each KR should be owned by the firm ("make"), made available by using suppliers ("buy"), or by associating with complementors and strategic partners ("ally"). This decision will depend on the nature of each KR. If the KR is absolutely critical to the business model and coherent to the firm's core competencies, it is likely that "make" will be the most appropriate choice. Conversely, if the KR is generic and not particularly linked to the firm's core competencies, contracting at arm's length with suppliers will in general make sense. The decision might be harder in the case of *non-core but co-specialized* KRs, which must be developed in a way that is specific to the firm and its business model. In this latter case, the firm will probably be unable to ensure the availability of these competencies by simple arms-length contracting with generic suppliers. These suppliers may not exist at all, since these KRs are firm-specific. Moreover, suppliers who could develop them might be unwilling to make the required investment, unless they have sufficient guarantees and a long-term commitment from the focal firm. In these cases, "ally" might be the most advantageous choice.

Making the right decisions at this point is quite critical to ensure the correct execution and profitability of the business model. Using resources coming from parties who are ineffective or inefficient, neglecting potential economies of scale and not considering risk, might in fact wreck the most beautiful business model one could conceive.

#### 7.2.1.9 Cost Structure (CS)

In general, the allocation of KRs to either the firm, to market-based transactions or to long-term partnerships, allows the definition of the business model's Cost Structure, which is the last section of the Canvas. This allocation allows the firm to understand and perform a preliminary evaluation of the distribution of its costs among the main cost categories (i.e., fixed, semi-fixed, and variable). Moreover, it will allow a preliminary estimation of economies of scale and economies of learning that might arise when operating the business model.

The evaluation of the business model's Cost Structure is a crucial point, since it is now possible to compare the CS with the RS and evaluate the degree to which the model is profitable or not. In most cases, profitability is not to be considered statically, since business models will usually be unprofitable at the beginning. So, a dynamic view over multiple time periods will allow the firm to consider the evolution of demand, revenue and cost, so that—hopefully—the initial investment may be recovered.

### *7.2.2 Using the Canvas in Practice*

From the short description given above, it is quite apparent that the Canvas is first of all a powerful discussion and communication tool, since it allows a synthetic description of a complex system such as a firm's business model. As such, the Canvas can be used in multiple ways and with quite some degree of flexibility. Among the many instances of use, it might make sense to focus on the four that are of greater relevance to innovation strategy.

#### 7.2.2.1 Using the Canvas in New and in Existing Firms

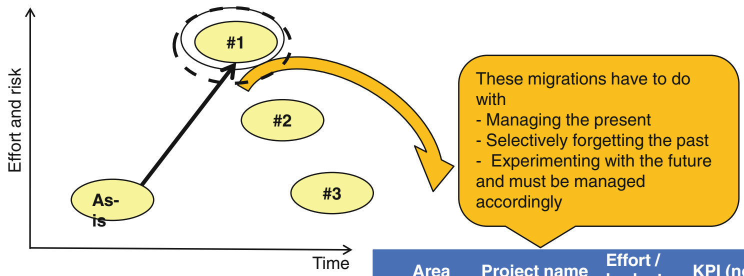
The Canvas can be used either for designing a business model from scratch, or for redesigning the business model of an existing firm.

In the former case, the team that works on the project will simply develop a single target business model or, better still, a set of alternatives to be compared with one another. In the case of existing firms, the team should start with a Canvas that faithfully depicts the current (or “As-Is”) business model, without yet trying to correct its possible shortcomings. Then, the “As-Is” Canvas can be critically analyzed, so that inconsistencies can be highlighted and improvements proposed, thus leading to the drafting of a new (“To-Be”) business model.

To make the migration from the starting point to the target business model possible, the team may also come up with a roadmap characterized by a number of intermediate business models. For new firms, this may first of all be needed to ensure a sustainable growth path for the enterprise. Moreover, the intermediate stages can be useful for making “field experiments” on the evolving business model. Intermediate business models can have the same role for established businesses as well. In fact, no company would ever give a “go ahead” to a strategy that would require a deep change to its current business model and a blind investment in a future but obviously quite uncertain one.

When the business model will progressively be implemented, the market will provide evidence on its actual attractiveness and sustainability. This evidence may suggest revisions—or even radical changes—to the planned business model. Introducing substantial changes to an intended business model that is not living up to expectations is called *pivoting*. Pivoting should not be considered as a failure, but simply as a part of the learning experience associated to the development of the business model itself.

As shown in Fig. 7.3, each move from one business model to the next can be expressed in terms of the projects that will have to be carried out for developing the




| Area | Project name | Effort / budget | KPI (now) | KPI (target) |
|---|---|---|---|---|
| Value Proposition | Project 1 | | | |
| | Project 2 | | | |
| Channels | Project 3 | | | |
| … | | | | |

**Fig. 7.3** Developing a migration plan for business model innovation

new components highlighted in the Canvas. Each project will be characterized by the time and effort required and by Key Performance Indicators (KPIs), so that a complete and detailed migration plan can be developed, along with the required budget.

When working on a business model Canvas, in both cases of existing and new firms, the team will need to go through a number of iterations before it comes up with a coherent and satisfying result. It is quite likely that, throughout these iterations, a subset of the elements in the business model will not change. Should this happen, the firm is recognizing such elements to be central to its business model. Identifying these central elements is important, because the firm can use them as the "pivots" around which a set of candidate business models may be generated and progressively adapted.

Which elements are going to be recognized as stable obviously depends on the circumstances in which the business model is being generated. Pivotal elements are the ones that the company considers to be at its "core", and capable of generating competitive advantage. In principle, it is possible to imagine three main starting points. If the firm wants to develop a business model and a strategy around what it recognizes to be its core assets and competencies, the KA and KR sections of the Canvas will be the first ones to be compiled and will remain stable during the development of the business model (Fig. 7.4, panel a). In other instances, a company may have developed a technology, a product, or a range of products, and endeavor to build a business model around them. In this case (Fig. 7.4, panel b), the stable reference point will be found in the VP section of the Canvas. Finally, a firm may consider its core strength to lie in the relationships it has with a reference market. In this case, the development of the business model will revolve around the elements in the CS, C, and CR sections of the Canvas (Fig. 7.4, panel c).

#### 7.2.2.2 Unbundling a Business Model

When working on the business model, and specifically on its supply side, one must take a number of "make versus buy versus ally" decisions, which have a bearing on the vertical integration of the firm. In some occasions, a firm may wish to consider a

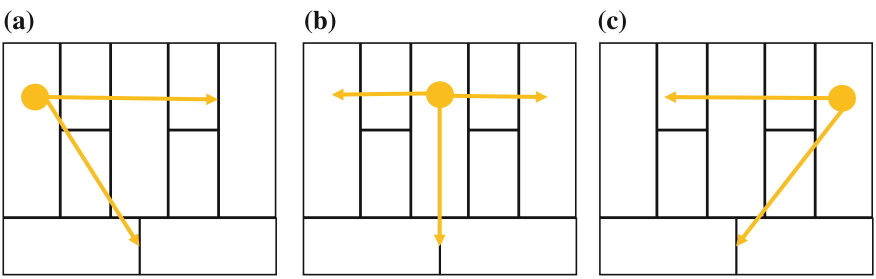



**Fig. 7.4** Pivoting around the recognized "core" of the firm

more radical perspective, which consists in the "unbundling" of its business model. Following Hagel and Singer (1999), businesses usually require the operation of three main processes. These are the development of new products (in the authors' original terminology, "product innovation"), sales (or "customer relationship management") and production (or "infrastructure management"). The authors argue that a firm will usually excel at one—or at most two—of these processes. As a consequence, companies should try to recognize their strengths and weaknesses and "unbundle" the processes that are not coherent with their core competencies. Unbundling can lead to decisions such as outsourcing them, spinning them off, or running them in partnership process with other organizations.

The Canvas can be a very helpful tool for studying a possible unbundling solution. To this purpose, one can tag elements in the KA and KR sections to associate them to the three processes mentioned above. Unbundling would then consist in making sure that the KA and KR elements pertaining to the processes that are recognized as non-core are associated to a Key Partner in the relevant section. Of course, such a change will affect both the Cost Structure and the Revenue Streams, and will therefore have to be evaluated with respect to its profitability.

#### 7.2.2.3 Competitive Benchmarking

One of the areas of the Canvas where analysts must ensure coherence is the relationship between VPs and CSs. It is in fact very easy to conflate VPs with a description of product quality that is biased by the firm's inner perception. To avoid this distortion, it could be in some cases advisable to perform an analysis at a deeper level. At first, the relevance of each VP to each CS should be analyzed in a rigorous way, making sure that no VP and no CS remain isolated. In visual terms, this can be easily done by using an incidence matrix such as the one shown on the right-hand side of Fig. 7.5.

This preliminary assessment can be supplemented by performing competitive benchmarking, to evaluate how the firm's actual and/or prospective products are able to deliver the VPs, and how they stack up when compared to competitors' offerings. This should be preferably done by using actual customer data but—that missing—self assessment can also be used. The comparison can be performed by using the profile chart on the left-hand side of Fig. 7.5.

#### 7.2.2.4 Scenario Analysis

Business modeling is usually a long-term and strategic endeavor that points quite far into the future. In the likely case that future and uncertain events might have a positive or negative impact on the inner coherence, or on the profitability of the business model being studied, it is advisable to perform a simple scenario analysis. The first step consists in identifying a limited number of significant dimensions of uncertainty and their potential outcomes. Dimensions of uncertainty can be

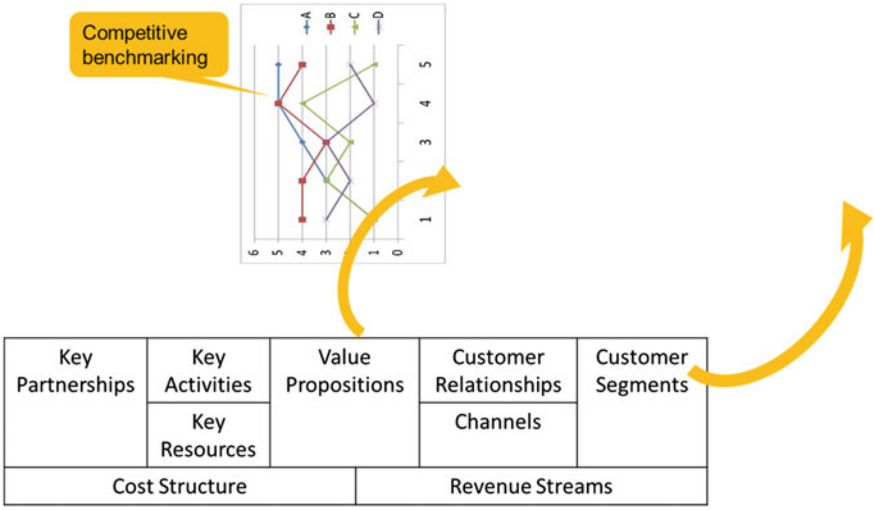



**Fig. 7.5** Analyzing and benchmarking value propositions against customer segments

associated to Policy, Economic, Social, and Technology (PEST) analysis. Examples of uncertainty dimensions can be the emergence of an enabling technology, the continuation of macroeconomic phenomena, or the adoption of a given policy decision. For simplicity, outcomes are defined according to discrete levels (i.e., outcome X may either happen or not; Y may lead to levels that are low, medium, or high, etc.). The combination of these outcomes allows the definition of a discrete number of potential scenarios (for instance, three uncertainty dimensions with Boolean outcomes will generate eight scenarios). At this point, the candidate scenarios can be listed, and the ones that are not considered feasible can be pruned out (i.e., outcome X may not be possible if outcome Y does not occur).

Once the feasible scenarios have been enumerated, the team may develop a Canvas for a number of alternative business models, which may be more or less applicable or attractive in each scenario. Once this has been done, it is possible to compile a comparison table mapping alternative business models with the possible scenarios and use it to select the business model to pursue.

### *7.2.3 Understanding the Coherence of the Business Model*

Throughout the previous discussion, it has been stressed that a business model is a conceptual description that has the aim of evaluating the coherence of its constituent elements. The validation of this coherence can be studied under different perspectives.

One first perspective for validation is simply semantic. The team that is performing the business modeling exercise can check that the elements that are being placed in the Canvas fit together according to business logic and common sense. Performing a thorough check at this semantic level is by no means a trivial task, since it is quite likely that—at first sight—the team will not be able to spot incoherencies. This is often the case, when the elements are not carefully and sharply worded.[5]

A second perspective concerns economic aspects, and consists in working at sufficient depth with the bottom sections of the Canvas, in make sure that expected revenues may cover costs. Of course, this is just a preliminary evaluation and not a full-blown business plan. However, if a rough-cut evaluation does not lead to a positive outcome, it is quite reasonable for the analysts to try improving the business model at this level, rather than going deeper in the financials, and hoping that things might improve by adding detail. The bottom section of the Canvas requires the team to operate on a quantitative—rather than purely qualitative—stance. This is only possible if some quantitative element has been introduced in the upper sections of the Canvas. Specifically, an estimation of revenues will require the definition of the following elements:

- An estimate of the size of each Customer Segment, starting from a *Total Addressable Market* (i.e., the universe of potentially interested customers in that segment), which must be whittled down to a *Served Available Market* that takes into account the existence of competitors and the inability of the firm to make its offering universally known and available. Then, this will be reduced to a *Target Market* made up of the most likely buyers, given the Channels and the effort that the firm intends to spend in customer acquisition.
- An attempt to set price levels according to the pricing scheme that has been decided. In turn, this requires a careful evaluation of the VPs in the eyes of the specific CSs. The value of the offering leads to a willingness to pay, which depends on the type of good or service that is being discussed. In some cases, value will have to be derived by comparison with other goods (e.g., a high-end watch may be compared to other watches and to jewelry). In other cases it may require to imagine being in the customers' shoes and make a Return On Investment or Payback calculation from their perspective (e.g., an energy saving device can be priced to make sure that the investment is paid back in a given time). Of course, firms should not forget to include sales taxes or VAT, which might significantly impact final consumers' choices.

[5]For instance, suppose that a fast food chain is trying to make a stab at the teen obesity problem by proposing a VP of "healthy and competitively priced fast food" to a CS of "poor and uneducated teenagers". A coherence check would make sure that the Channel is appropriate to the VP and CS, and it would probably be better to have "neighborhood outlets" rather than "premium outlets in fashionable streets". Moreover, the business model would be incoherent if the firm did not add some element in the Customer Relations section aimed at making sure that the CS will acquire a greater appreciation of this particular VP. Note that this quite important issue could easily be overlooked, if the CS had not been precisely labeled with the adjective "uneducated".

- The intermediation costs associated to the Channels that are being chosen. So, indirect sales will be dominated by the markups that are added at each tier, leading to a significant decrease in the revenue available for the focal firm. Conversely, direct sales will be characterized by "customer acquisition costs" that will not impact the revenues, but will certainly increase the costs.

On the side of costs, the analysis will be carried out by considering:

- Key Activities and Key Assets that the firm has decided to perform internally and own, and which will lead to a set of fixed costs (due to capital expenditure needed to buy the assets) and variable costs (due to operational expenses in running them). These costs will also depend on the capacity that is required, which is directly tied to the sales estimates that have been made on the demand side of the Canvas.
- Key Partnerships will also lead to a set of fixed and variable costs, which will depend on the level of specificity of the activities that will be performed by the partners. In general, the higher the degree of specificity, the higher the investment that the focal firm will be required to make.
- General and Administrative expenses that are not being explicitly considered by the business model, but that will nonetheless impact the firm's Profit and Loss statement.

A third and slightly more complex approach to checking coherence in the business model is based on studying causal connections between its elements (Casadesus-Masanell and Ricart 2010). This can be done in a structured way by using Causal Loop Diagrams (CLD). These diagrams consist in a graphical and qualitative representation of the relationships between variables in a complex system. Variables are represented as nodes in a graph, and arrows represent causal relations between variables, with the + or − sign indicating the direction of the relationship. A positive link from variable A to variable B means that if A increases (decreases), B will increase (decrease). Conversely, a negative link will indicate that if A increases (decreases), B will decrease (increase). Figure 7.6 shows a very simple example of a CLD that represents a few elements that could make up a business model for a premium grocery store.

CLDs are generally used as a preliminary step for structuring a complete and quantitative analysis under the Systems Dynamics approach (Sterman 2000). However, they can be also used to achieve a qualitative understanding of system behavior. Specifically, observing the loops in a CLD, it is possible to identify whether a phenomenon is likely to lead to self-reinforcement or to a balanced equilibrium. The former occurs when the number of negative links in the loop is even (including zero), since no causal effect will stop the variables from moving in the same direction. Conversely, a balanced equilibrium will arise if the number of negative links in the loop is odd.

When using CLDs to represent business models, it may be helpful to distinguish between rigid and flexible causal links, to have a better appreciation of the velocity of the dynamics that is involved. In a rigid link, the impact of A on B is quick,

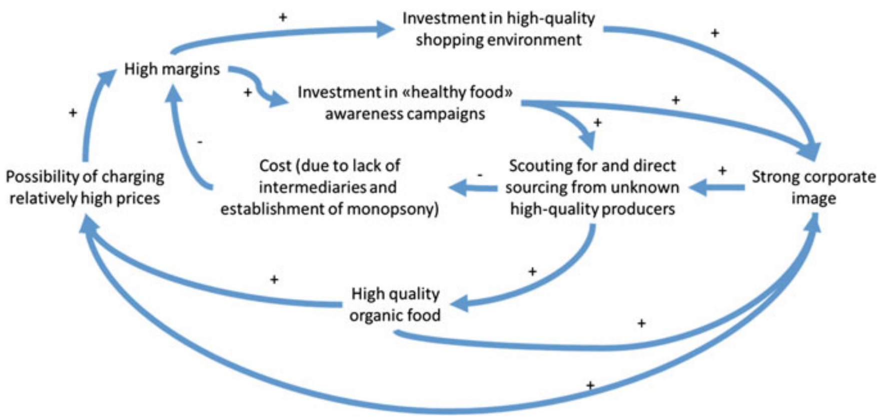



**Fig. 7.6** Using a causal loop diagram to study the coherence of a business model (case of a premium grocery store)

whereas a flexible link will lead to a slower impact. For instance, it is likely that price changes may impact demand quite rapidly, while product quality will allow a much slower development of reputation. When analyzing a business model CLD, it is particularly interesting to identify virtuous circles, or self-reinforcing loops. These loops can be viewed as the main sources of competitive advantage of the business model, since they allow the firm to progressively improve its profitability and generate barriers to entry, since imitating firms will find it difficult to catch up on the same path. At the same time, the elements that make up the virtuous circle are to be viewed as particularly critical, since any breakdown that might occur would likely lead to the demise of this competitive advantage.

## 7.3 Representing a Business Model from the Perspective of a Value System—E3value

Up to now, the discussion has dealt with representing business models from the perspective of a focal firm. Nonetheless, the Canvas described in the previous section has made it clear that not all activities pertaining to the business model will actually be carried out by a single company, and that Key Partnerships will have to be defined to make the model operational. In fact, Zott and Amit (2010) have stressed that "*business models are boundary spanning systems of activities centered on a focal firm*".

So, given that business models cannot be fully understood if not by looking beyond the boundaries of the focal firm, the same firm must make sure that the relevant activities and partners are not only listed, but that they can actually work as a coherent whole.

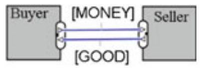
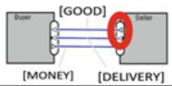
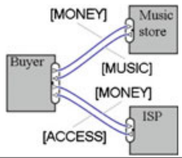
To achieve this result, it is possible to use business modeling tools that broaden the perspective to the entire *value network* within which the firm is operating in. The term "value network" is purposely used as an extension to the familiar concept of "value chain", since the relationships between the participating entities may not necessarily be linear, as the term "chain" would imply.

Among these modeling tools, it is possible to introduce e3-value (Gordijn and Akkermans 2001), a tool that strikes an interesting balance between modeling power and ease of use. e3-value can be viewed as a dialect of UML (Huemer et al. 2008), a systems modeling language that is widely used in the field of software engineering. With respect to UML, e3value proposes a simplified notation and approach. Moreover, e3value focuses on describing the multiple actors involved, the main value-creating activities they perform, and the related exchanges of goods, services, and financial resources. It does not consider the minute description of the activities being performed, since the aim is to suggest strategies to business managers, rather than to provide technical specifications to system developers. The language has been used in many different applications, a survey of which can be found in Pijpers et al. (2012).

The main idea behind the e3value approach is that complex business models arise out of the cooperation between multiple actors, which are jointly engaged in providing products and services to one another. This allows value creation through two avenues. One is the "traditional" approach of adding value to inputs and selling the outputs, and the other is the exploitation of complementarity between activities and the associated outputs. Especially when working with this latter form of value creation, it is critical to make sure that activities and their pricing are structured in a way that all actors are left with sufficient economic margins, thus making it profitable to take part in the overall value network. For instance, consider the managers of a magazine, who must decide on the pricing of space given to advertisers, the number of pages assigned, and the type of advertisers accepted. These three elements must be structured in a way that will provide advertisers a return on their marketing investment, at the same time making sure that the readers will not be annoyed by commercial content and therefore reduce their willingness to pay the cover price.

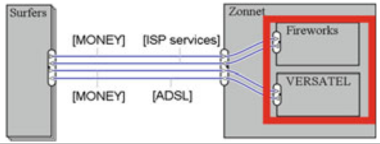
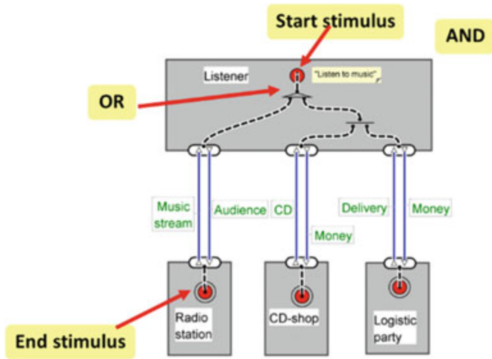
In this type of context, the focal firm will have a central role in coordinating the business model, but this will not amount to having formal authority over its partners. Therefore, it is only through the attractiveness of the business proposition offered to each actor that partners will be drawn to the business model and take part in the value creation process. Therefore, when considering a business model that straddles multiple firms, it is not enough to work on a purely conceptual point of view (i.e., making sure that relevant parties are listed, and designing their functional interactions). Conversely, one must consider—at least at a high level of abstraction—financial flows as well. This means moving from a conceptual business model to a

**Table 7.1** The main elements in the e3value notation

| e3value construct | Definition | Example |
|---|---|---|
| Actor | An economically independent entity that acts within the value system. An actor can be a consumer, a firm, or a business unit of a firm. |   |
| Value object | An entity that has economic value to an actor and is exchanged within the value system. Value objects can be physical or not (e.g., immaterial services). Money is a value object. |   |
| Value port | Represents the way a value object goes in (i.e., is consumed) or out (i.e., is produced) by actors. |   |
| Value offering | A value offering is a grouping of value ports that are equally directed. They definitively represent a bundle. |   |
| Value interface | In each actor, the value interface represents the grouping of incoming and outgoing value offerings. It represents reciprocal exchange among actors. |   |
| Value transfer | Connects two value ports together, and represents trade between actors |   |
| Market segment | Is a grouping of actors who exhibit strong similarity in the way they assign economic value to objects |   |

(continued)

**Table 7.1** (continued)

| e3value construct | Definition | Example |
|---|---|---|
| Value activity | Represents activities being carried out within each actor. It allows to separate the “who” (i.e., the actor) from the “what” (i.e., the activity) and to fully describe authors that carry out multiple activities |   |
| Actor compositions | Represent groupings of actors that partner together tightly. For instance, an actor composition might expose a single value offering to customers, in a way that the latter are not aware of which actor provides what value object. |   |
| Dependency path | In the case one wishes to add detail, a dependency path shows the order with which value transfers occur. The path has a starting point in which a stimulus is originated, and has an end. The path progresses from the origin to the end by replying to the question “how can this happen?”. Conversely, one can trace the path from the end to the stimulus by replying to the question “why is this happening?”. The path may branch through OR gates (when a stimulus is satisfied through one mean or another one) as well as through AND gates (when a stimulus is satisfied through one mean and another one). |   |

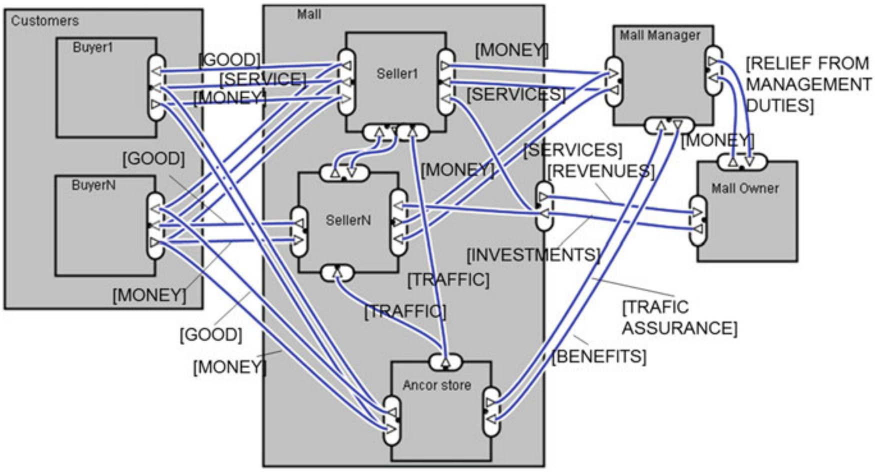



**Fig. 7.7** A sample e3value model

preliminary business plan, which must be drafted to highlight the profitability for each individual partner and for the value system as a whole.

e3value provides a graphical notation and, through its software embodiments, a tool that allows covering these requirements. The following Table 7.1 provides a synthetic overview of the notation, while Fig. 7.7 provides a sample representation of a business model.

In Fig. 7.7 it is possible to see a sample e3value model that depicts the business model of a shopping mall, and which exhibits a number of the constructs discussed above. When using the e3value editing tools, analysts can not only create a graphical description of the value system, but also provide basic information leading to preliminary business plans. Specifically, one can input information on flows (i.e., demand that a market segment will generate for a given value object) and value (i.e., cost/price data associated to value objects, as well as fixed and semi-fixed cost data associated to activities). This can lead to the automatic generation of financial spreadsheets representing the basic financial flows occurring to each actor which—as mentioned before—can provide a preliminary evaluation of the viability and attractiveness of the business model.

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# Chapter 8
# Innovation Strategy as the Management of Competencies

Chapter 6 ended with a comprehensive model of innovation strategy, which based this element of corporate strategy on two main pillars. The first pillar was the definition of a desired portfolio of competencies and the planning of their development. The other pillar was the outlining of a portfolio of product and market development activities. This chapter will cover the former pillar, while Chap. 9 will tackle the latter.

## 8.1 Mapping and Planning a Competency Portfolio

In order to manage and develop the competencies portfolio of a firm, the first issue to be solved has to do with classifying and assessing competencies. There is no fixed rule in performing this exercise, and each firm will be likely to develop its own method.

Competencies have been defined as the organizational routines that involve resources, but it is obviously difficult to objectively classify and measure routines. It is therefore easier to work on the resources and assets that are being used by the company. The firm can therefore define a directory of relevant competencies (e.g., for an IT company, one could think of a list of technologies and programming languages that it uses) and then make an inventory of the *resources pool* that are associated to each. A firm may therefore consider its human resources and use the headcount of employees who share a same competence. In the case of competencies requiring capital-intensive assets, the company could also use fixed assets (e.g., the book value of laboratory equipment associated to each competency). Alternatively, in the case of industries where intellectual property is highly relevant, the firm could list competencies by using patent classifications and then measure them by counting its patents.

Just as in product portfolio management, visual tools such as bubble charts can be quite useful to support the representation of competencies. Management will identify two axes for locating each competence, and the size of the related resources pool will be represented by the diameter of the bubble (see Fig. 8.1 for an example).



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_8

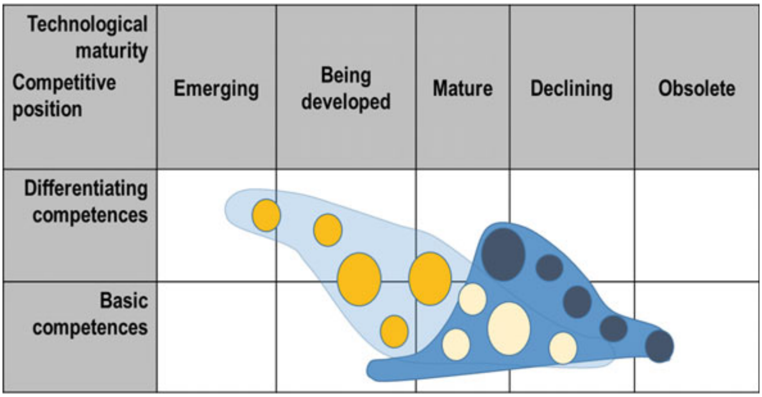


**Fig. 8.1** An example bubble chart representing an "As-Is" portfolio of corporate competencies (area to the right) and a "To-Be" one (area stretching *top left* to *bottom right*)

The choice of the axes depends on the objective of the analysis, and candidates include technological maturity, competitive impact of the competence, relatedness to the firm's core competencies, perceived risk, etc.

By looking at the bubble chart representing the current competencies portfolio ("As-Is"), it will be relatively easy for management to identify which competencies have to be strengthened, developed, or progressively decreased or decommissioned, thus outlining a desired ("To-Be") competence portfolio. Of course, the chart is only a visual tool, and the analysis will have to rely on an adequate understanding of innovation and competitive dynamics in the specific industry, together with a general idea of strategy at corporate level.

From an organizational perspective, the development of competencies is a process that requires relatively long time constants. It must be therefore undertaken on time, since it will probably be too late to start acting when the firm perceives its competitive advantage to be faltering. Moreover, managing competencies implies operating at a deep level within the firm, and considerable inertia and resistance to change are likely to emerge as a reaction. Firms might therefore think of staffing their top management teams with a balance of executives representing the firm's past (who are likely to have been promoted from within the firm) along with managers representing future needs and directions (who may be recruited from the outside, or be chosen among insiders who have followed somewhat less orthodox career paths).

When managing competencies at a strategic level, one may wonder what constitutes a "good" portfolio of competencies and resources with respect to size, scope, and experience. The academic debate on this issue can be quite confusing, but researchers seem to agree that economies of scale do exist (Macher and Boerner 2006). In other terms, firms with larger pools of competency-related assets are likely to achieve better results, because of greater variety among resources of the same kind, and because critical resources can be used with higher efficiency. When looking at scope, i.e. the number of different competencies listed in the portfolio, two elements must be taken into account. Greater diversification leads the firm to lose focus, which has a detrimental effect. However, a wider scope also provides room for spillovers between different competencies and, when uncertainty is very high, increases the likelihood of having "the right competencies at the right time".[1] Following Macher and Boerner, the net impact of these two opposing effects depends on experience, since the ability to capture opportunities due to spillovers and chance will be greater for firms that have built substantial experience in the related fields. It comes as a corollary that startup firms ought to be more focused, while mature firms will benefit by progressively expanding their competency portfolio.

The bubble chart representing a competencies portfolio can be developed by looking only at the firm being analyzed. However, it can also be used for competitive benchmarking, by placing it side by side with a similar chart representing—possibly with some approximation due to lack of information—selected competitors.

Managers might also decide to map the competencies of the entire value network the firm is part of. This allows to work on knowledge partitioning within the chain, and to support a broader innovation strategy that may also involve key players operating in its ecosystem. Working at this level will make it possible to identify whether competencies have to be developed internally by the firm ("make"), by using selected suppliers ("buy") or by associating with complementors and customers ("ally"). This decision will depend on the strategic stance that the firm has with respect to each competence. Clear decisions can be taken if the competence is recognized to be *core* (in-house development will obviously be recommended in this case) or *non-core and generic* (contracting with generic suppliers will in general make sense, unless cost analysis suggests differently). The decision might be somewhat more involved in the case of *non-core and co-specialized* competencies, which must be developed in a way that is specific to the firm. In this latter case, the firm will probably be unable to ensure the availability of these competencies by simple arms-length contracting with generic suppliers. These suppliers may not exist at all, since the competencies are firm-specific. Moreover, suppliers who might be in the position of developing these firm-specific competencies might be unwilling to make the required investment, unless they have sufficient guarantees and long-term commitment from their customer. Therefore, the firm will have to decide between internal development and forging long-term agreements with other actors. It comes without saying that failing to identify the need for co-specialized competencies can be one of the most damaging mistakes a company might make in drafting its strategy.

Once the desired competencies have been identified, the firm must decide on the best way to develop them. A variety of approaches is available, and will be described in detail in the following sections of this chapter. The approach to choose will have to be decided case by case. In general, firms may work on two main trade-offs. The first trade-off is between the time required to develop the

[1] Leiponen and Helfat (2010), use the analogy of buying tickets to a lottery.

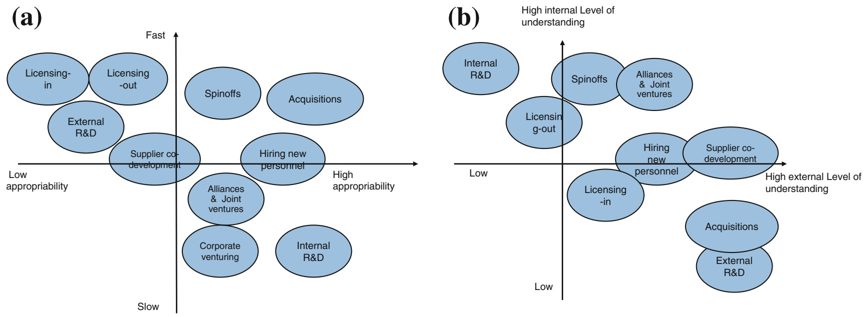


**Fig. 8.2** The main trade-offs in choosing an approach for competency development

competencies, versus the economic appropriability of the related benefits (Fig. 8.2b). A second trade-off is between the level of understanding that is possessed by the firm and by external parties (Fig. 8.2a).

Aside from these considerations, a last and crucial aspect that has to be considered is the firm-specific capability of executing a given strategy. In fact, it does not make any sense for a company to pursue a strategy that—in principle—is the most appropriate, if the firm does not have the experience or the skills required to implement it. For instance, should an acquisition appear to be more suitable than a strategic partnership in developing a desired competency, managers should ask themselves whether the firm has any experience at all in running such a complex process. If not, it might be advisable to choose the second-best option.

## 8.2 Internal Research and Development

The traditional and mainstream way to grow a desired competency was to develop it internally by allocating resources—human, material, and financial—and having them execute research and development projects. Nowadays, this still is a common and powerful approach, but must constantly be assessed against the other means described in this chapter.

### *8.2.1 The Relationship Between R&D Expenditure and Corporate Performance*

In business and in economics, it is still customary to use R&D expenditure as a proxy for measuring the degree with which a specific firm or an entire economy dedicates itself to the growth of its knowledge base. In the former case, one will commonly use the ratio between R&D expenditure and sales[2] and—in the latter—the ratio between R&D expenditure and GDP. These ratios are often used as indicators for the innovativeness of firms and economies, which is of course a mistake, since they conflate an input (investment) with an output (innovative performance). As a matter of fact, when considering R&D activity at corporate level, one can wonder whether this effort is causally linked to corporate performance—which seems to be a highly popular view—or not. Research on this question has always come to the conclusion that the link between R&D intensity and corporate performance is highly ambiguous.

The traditional explanation justifying this correlation is that R&D activity provides both direct and indirect benefits. The former consist in the development of innovative technologies and products, potentially leading to competitive advantage. Indirect effects consist in increasing the firm's absorptive capacity, which makes it more adept at using externally developed knowledge and/or in imitating competitors.[3]

An alternative position (Knott 2008), considers the firm's *organizational intelligence* (i.e. its capability of changing and adapting its resources and routines) as an important mediating factor. A firm with high organizational intelligence will be able to capture opportunities coming from the knowledge generated by R&D activity, and it will be therefore appropriate for such a firm to make this kind of investment. Conversely, a firm with low organizational intelligence will not be able to extract value out of R&D and should therefore avoid committing too many resources into it.

Other authors (Li and Hwang 2011) have identified financial leverage (i.e., the level of indebtedness) and demand fluctuations as another important mediating factor. The argument is that R&D is likely to deliver positive results only if projects are assured stable financing throughout their duration. Now, a highly indebted firm will risk not being in the position to provide a stable R&D budget since—should demand turn down because of the business cycle—the need to service debt will force managers into reducing non-essential expenditure, among which R&D. Should this occur, the firm would terminate projects before they are finished, without receiving any benefits, and having wasted the money spent to start them. Moreover, a firm with high leverage may use debt to finance projects related to material assets that can be put up as collateral—such as buildings or generic production equipment—but not to immaterial assets such as the ones originating from R&D.

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[2]In the case of small firms, this ratio is sometimes meaningless, and it might therefore be advisable to use the frequency of R&D activity, rather than its intensity (Cuervo-Cazurra and Un 2010).

[3]One might also put forward a somewhat more cynical argument, stating that the correlation does exist, but with a reversed causal link. The claim would therefore be that profitable firms have ample financial resources and tend to overinvest in R&D. Thanks to this effort they occasionally get some significant results that allow to increase an already existing competitive advantage and—when they don't—the investment made is usually not so large to cause a significant decrease in performance.

Finally, firm size also can play a role in determining the R&D intensity of a company. R&D lends itself to significant economies of scale, since the higher the sales, the more the investment will be spread over each unit sold. Moreover, given the risk associated to R&D projects, a large firm with a large portfolio of projects will face less aggregate risk than a small firm working on a few projects only. It is therefore obvious for small companies to invest less R&D money than large ones. Exceptions can be found for small firms that enjoy substantial contribution margins, or that anticipate a significant growth path as a consequence of this investment and have investors willing to face the associated risks. Furthermore, many R&D activities are internally characterized by economies of scale and by minimum efficient scales. For instance, a given activity may be carried out only by purchasing costly lab equipment and/or by hiring a group of researchers with distinct specializations. It is obvious that only a large firm would be in the position to support such an investment from both financial and economic perspectives. A smaller firm, able to spend less than the required sum, would not have a competitive laboratory and would not reap results from it.

### 8.2.2 *Some Typical Features of R&D Activity*

When evaluating the appropriateness of using internal R&D projects to build new competencies, a few elements must be considered. As a starting point, the main advantage of internal R&D is the high degree of appropriability of the competencies generated. This must however be compared against a number of other critical aspects.

One first issue to be tackled is the definition of the amount of R&D to be budgeted by the corporation or by the business unit. In general, it is not trivial to identify and compute the financial returns coming from R&D investment, which makes it difficult to define an "optimum" amount to be spent. Companies therefore tend to rely on ballpark figures that associate the R&D budget to other variables (e.g., R&D/sales or R&D/profit) and making comparisons with their competitors in the same industry. Therefore, it has become customary to work on "standard" and industry-specific R&D/sales ratios, such as the 11–12 % used in R&D-intensive industries such as software and pharma, 8 % in electronics, 4–5 % in automotive and aerospace, etc.

Internal R&D is not only a matter of the amount of money that is being spent, but also of the way it is spent. Specifically, path-dependency can limit the capability of the firm to develop new competencies that are far away from its existing knowledge base, or to do so in a reasonable time. Especially if top management is not knowledgeable in technology, internal resources will be in a strong position allowing them to effectively block efforts that imply a significant deviation from established competencies ("*you know, we've tried it, but it doesn't work. Do you really want us to try again?*"). The so-called *Not-Invented-Here Syndrome** is not a representation of intellectual laziness, but is simply due to the fact that internal resources will find it much easier and be more productive to continue with the old competencies and technology, rather than going for new ones. Consequently, unless there is a clear mandate with strong incentives and suitable organizational arrangements to pursue the new competencies, they will tend to fall back on the old ones. One can therefore conclude that—unless it is managed very carefully—R&D is best suited for long-term endeavors and/or for achieving competencies that are not too distant from the firm's current ones.

When considering R&D projects, the issue of worker productivity and incentives is of capital importance. In fact, when dealing with intellectual work in general, it is difficult to measure productivity. The difference between a brilliant and highly motivated employee and a mediocre and dispirited one can be very high, and the firm should consider whether its R&D personnel are delivering as much value as their salaries are worth. Concerning incentives, financial rewards and career opportunities may matter, though research tells us that R&D personnel are motivated by other aspects as well, such as intellectual challenges and independence (Sauermann and Cohen 2010). At the same time, management should consider that R&D results are correlated with quality of effort, rather than to quantity, and this calls for sophisticated approaches for measuring worker productivity. Unfortunately, the type of results that firms and their R&D personnel aim to achieve may also differ. As noted by Xiaoying et al. (2009), firms will push to develop highly specific know-how, since this increases the sustainability of its competitive advantage and reduces the market value of human resources at the center of these competencies.[4] Conversely, the employees involved in R&D will tend to generate broader and more generic competencies. The firm will therefore constantly risk losing key personnel, who might leave for a competitor or start their own business right at the time at which results of R&D investment may be reaped.[5]

### *8.2.3 Positioning R&D Activity in Large Firms*

In the case of large and differentiated firms organized around a number of Business Units (BUs), management must take a strategic decision concerning the organizational positioning of R&D units. Two solutions are traditionally available, with either a *centralized* R&D unit serving all BUs (Fig. 8.3a), or having *decentralized*

[4]If a firm develops competencies that have the same value to any firm in the industry, employees will have a strong bargaining position, since they could command a much higher salary by shopping around for a job and trying to extract all the economic value of their know-how, or simply threatening to do so. This would not be possible if the value of their know-how is specific to their current employer.

[5]Firms may introduce *Non-Compete Clauses* in employees' contracts. However, these clauses are generally quite difficult to enforce since—if they are too strong—courts might simply reject them as invalid.

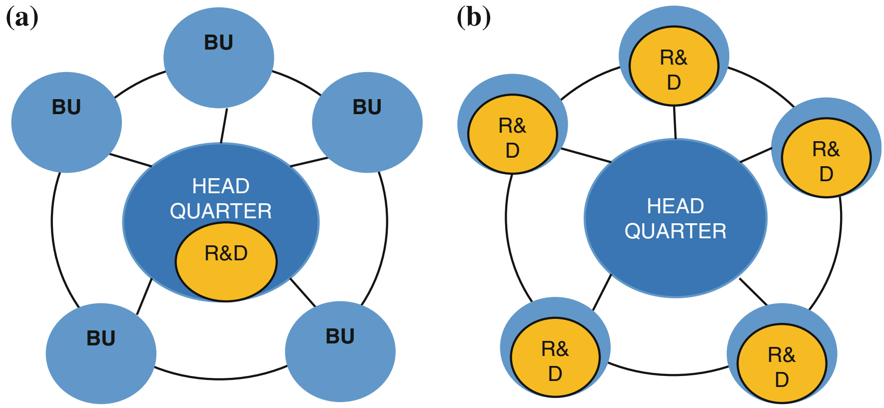


**Fig. 8.3** Centralized and decentralized R&D in large firms

R&D units in each BU (Fig. 8.3b). Deciding on which alternative to follow implies finding a trade-off between advantages and disadvantages of each.

The main advantages coming from centralization of R&D are related to economies of scale. A single unit with a critical mass can make better use of costly resources, create strong links to the scientific community, and provide interesting career incentives to researchers. Moreover, centralized R&D activity leads to greater chances of spillovers (i.e., sharing the results of a project among other projects and among BUs), at the same time avoiding duplication of effort. In decentralized R&D, the latter is a constant problem, since it is very common for BUs to develop similar projects at the same time without each BU being aware of the other BU's activity. Finally, with centralized R&D, strategic guidance and budgets are defined by the firm's top management, which ensures greater financial stability, a longer-term view, and alignment with corporate strategy.

Against these clear advantages, centralized R&D units also have disadvantages. A first drawback is connected to the geographical centralization of an R&D unit, which may limit the possibility of accessing talented researchers that live elsewhere in the world.[6] A second disadvantage is associated to the risk of falling into the so-called *ivory tower syndrome*. This occurs when researchers work on highly challenging and potentially promising projects, but fail to make an effective connection with BUs and their needs, so that few results ever make it into product development.[7]

[6]Access to talent, both in terms of recruiting employees and in establishing connections to academic centers of excellence, is a key problem in industrial R&D. It therefore follows that large companies will tend to locate their R&D centers in areas where talented individuals can be found or attracted because of either academic quality and/or quality of life.

[7]A well-known example is Xerox's Palo Alto Research Center (PARC), which the multinational purposely created close to Stanford University and far away from its corporate offices in New York State in 1970. PARC researchers came up with many groundbreaking inventions in the field of computing, such as Graphical User Interfaces, text editors, and Ethernet networking technology.

To avoid this ivory tower effect, large firms have devised with a number of organizational structures and mechanisms. First, a constant flow of information between the R&D center and BUs can be promoted using both IT tools and corporate events, similar to trade fairs, for matching research results to business needs. Co-financing mechanisms can also be used to ensure that R&D projects are meaningful to BUs. For instance, the R&D budget may be split between the research center and the BUs, and the former can be allowed to start a project only if it convinces one or more BUs to use their budgets to co-finance it. Organizational mechanisms can also help, for instance by favoring mobility of BU and R&D personnel and managers. Another approach is to introduce a matrix organization in the research center, so that managers with BU experience are in charge of budgets and project portfolio definition, while managers with scientific background are responsible for human resources and running projects. Finally, very large firms may introduce a hybrid organizational structure for R&D, with both centralized and decentralized R&D centers. The former centers focus on individual technologies and work at a more fundamental level. The latter ones are localized within each BU and work on applied research projects that are closer to business needs and act as a bridge to product development.

Firms can also complement their R&D structures with other organizational mechanisms that can provide additional incentives to personnel that belong to the R&D and/or to operational functions. Some firms allow their staff to use some 10–20 % of their time to pursue personal projects. This is usually connected to *intrapreneurship* schemes, in which employees whose personal projects show promising results can act as "internal entrepreneurs" and are given the chance to bring them toward actual development, thus managing progressively higher budgets and responsibilities.

In other cases, company may promote *corporate spinoffs**. Spinoffs provide a powerful incentive to employees who may be considering starting their own business, since the originating firm can be a very useful shareholder, providing finance and the complementary assets that a startup would typically lack. Spinning off a new company can allow the further development of projects that are non-core to the firm and would probably not go into development if kept inside, because of strategic misalignment, organizational inertia, or because they would require the participation of other financial or industrial partners. Besides, the firm avoids completely losing the competencies that an employee might bring with her if she decided to start an independent company.

The decision on whether to develop a new project internally or externally can be analyzed by considering three main factors (Cassiman and Ueda 2006). The first factor is the intrinsic value of the project $V$ (i.e., the economic value to the employee

(Footnote 7 continued)

All these inventions could have given Xerox a strong lead in the IT industry, but none of them were actually exploited. Through licensing deals, they contributed to Apple Computer's initial technology.

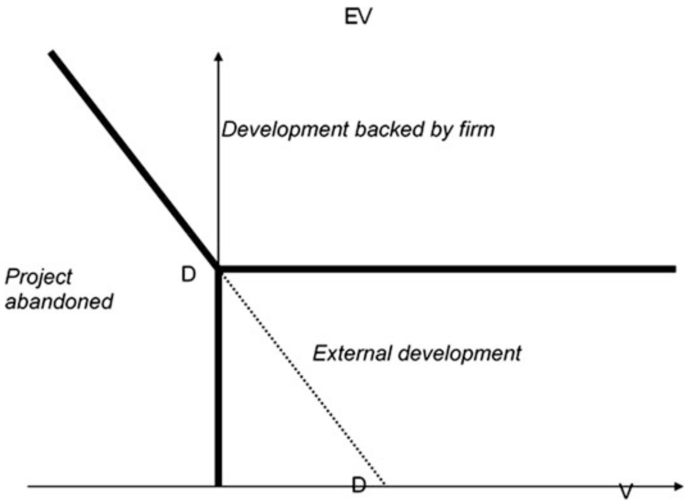


**Fig. 8.4** Trade-offs in external versus internal development of projects

deciding to leave the firm and founding an independent startup). The second factor is the extra value *EV* which can be achieved if the firm backs the project and allows the use of its assets. The third factor is the discounting *D* with which the firm will consider the project when evaluating it. This discounting can be due to the opportunity cost of committing resources to this particular project, the cannibalization of the existing business, and the inability to fully understand the value of the new project. The firm will decide not to back development if $V + EV - D < 0$ while the researcher will not start a venture if V < 0. As shown in Fig. 8.4, the combination of these two decision rules leads to three possible outcomes.

If $V > 0$ and $EV > D$, the project will be backed by the firm while, if $EV < D$, it will be developed externally. If $V < 0$ and $V + EV - D > 0$ it will be backed by the firm while, if $V + EV - D < 0$, it will be abandoned by both parties.

## 8.3 Technology Acquisitions

Acquisitions are a common event in corporate history and can occur for many different reasons, such as gaining access to a market or a customer portfolio, securing physical assets (e.g., plants and machinery), or obtaining desired competencies. The latter case is often referred to as a *technology acquisition*.

Acquiring an existing firm represents a very quick way for an innovation-oriented firm to obtain desired competencies, and to do so with a high degree of appropriability (Zhao 2009). In general, acquisitions can create value in both cases of the acquiring and the target firm having similar knowledge assets, or different and complementary ones. The former case typically supports incremental innovation, while the latter can be an avenue for radical innovation (Makri et al. 2010).

Acquisitions are characterized by a complex process that involves significant *transaction costs**.[8] The process usually entails four steps. At first, the acquirer must *scout* for target firms that might have the desired competencies and be open to be acquired. Then, it must perform technical and business *due diligence* to estimate the true value of the target firm, under the dual perspective of a collection of technological assets and of an ongoing business. Finally, it must *negotiate* the terms of the acquisition and—finally—it must *integrate* the acquired firm.

Integration means blending the two organizations together so that they perform together as a single entity. Following the evolutionary theory of the firm we are familiar with, the organizational routines that define both companies will have to be modified so that the acquired firm's resources act together—and within a new set of routines—with the acquiring firm's ones. In the case of technology acquisitions, integration is a somewhat paradoxical process. The acquiring firm buys another firm because of its competencies, but cannot fully benefit from them until it destroys them to merge them with its own competencies. Because of path dependency, the integration process is complex and may yield uncertain outcomes. Especially when the acquired company is large—as it often happens when an incumbent attempts to deal with a technological discontinuity—the new organization will have to deal with considerable inertia coming from both organizations, thus potentially impairing the potential synergies or delaying them significantly. Moreover, integration may fail if *resource retention* strategies are not correctly defined and key employees of the acquired firm—either because of uncertainty, or because they don't like the idea of working for the new firm—decide to leave. While full integration may require time in order to fully provide the economic value sought, the acquired firm remains an operational entity in its own right. Therefore, the acquiring firm will nonetheless be able to reap some benefits while it is still performing the integration process.

In many cases, technology acquisitions are subject to the so-called *winners curse**.[9] Following Ransbotham and Mitra (2010), when a firm is being considered for an acquisition, its shareholders will value it at an intrinsic enterprise value $EV$.[10] A prospective acquirer $i$ will value it at a reservation price $RP_i = EV + VS_i - CI_i$,

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[8]In economics, a transaction cost is the cost incurred to take part and to execute a business transaction, on top of the price paid.

[9]When an asset is sold at an auction, each candidate buyer will participate knowing her *reservation price*, which is the maximum price she is willing to pay for the good. Reservation prices are participant-specific, since each potential buyer will value the asset differently to the others. The auction will end when a bid is made, that is marginally higher than the second-highest reservation price. Therefore, when someone wins an auction, he discovers that he was the participant willing to the pay the most and that he ended up paying something above the second-highest reservation price. The term *winner's curse* represents the likelihood that the asset has been overpaid.

[10]Enterprise valuation can be performed in many different ways. Especially in the case of young, technology-based firms with significant growth prospects, it is common to consider the Net Present Value of the expected future profit stream, discounted by an appropriate risk-adjusted interest rate.

where $VS_i$ is the value of the acquirer-specific synergies or growth options that the acquisition might lead to after integration is performed, and $CI_i$ is the cost of the integration process. For a technology acquisition, the asset being sought is a set of competencies and its value-creating potential after integration and—especially if the acquirer is much larger than the target firm—it is possible for $RP_i$ to be orders of magnitude greater than $EV$. The parties will negotiate an acquisition value $AV$, which will lie somewhere between $EV$ and $RP_i$. If there is only one potential acquirer, it is likely that $AV$ will be higher than, but nonetheless quite close to $EV$, since the target firm will not have many levers available to negotiate a higher price. The scenario might change significantly if the target firm manages to have more than one potential acquirer enter the scene, thus starting an auction-like process. In this case, the acquisition value will become marginally higher than the second-highest reservation price $RP_{i'}$. If the value of the target firm's competencies is not specific to the highest bidder, the two suitors' reservation prices will not differ substantially, and the acquisition value can become much higher than $EV$. This brings potentially huge benefits to the shareholders of the acquired firm, and a real risk to the winner that the benefits of the acquisition might not materialize as foreseen.[11] Many acquisitions in the high-tech industries follow this process and lead to outstanding prices, such as eBay's acquisition of Skype in 2005, or Facebook's acquisition of Oculus Rift in 2014. Of course, acquirers will try to avoid the auction process by imposing a short timeframe to conclude negotiations and asking the target firm to grant exclusive negotiations (a *no-shop agreement*). Therefore, firms that feel they could become interesting acquisition targets will try to preempt this kind of request by starting as many informal talks as possible with potential acquirers, before being formally approached by any one of them.

In summary, acquisitions are a powerful, quick, but somewhat risky way to gain access to desired competencies, which itself requires a capability to execute them correctly and profitably.[12] From the perspective of target firms, the popularity of acquisitions as a way to gain competencies and technological assets, and the potentially high valuations at which these transactions can occur, often makes being acquired a strategic objective in its own right. Many entrepreneurial teams in startup firms tend to define strategies whose main objective is to rapidly make the company attractive for an acquisition (an *exit event*), rather than to achieve long-term growth. This particular way of conceiving entrepreneurship is often termed *serial entrepreneurship**. It is very common in the case of high-tech firms that are backed by

[11]Bidders may also increase their reservation prices by an additional amount that takes into account the competitive value of excluding a competitor from acquiring the target firm. The phenomenon is similar to what happens in professional team sports, when well-funded clubs pay outstanding sums for high-performing athletes even if their roster is already competitive ("it's better for us if X sits on our bench, than have him on the pitch, but playing against us").

[12]Cisco is one quite well-known example of *serial acquirer*, who has acquired and successfully integrated more than 150 companies between 1993 and 2013. When a firm's innovation strategy leads to acquiring an average of more than one firm each month, the acquisition process itself becomes a routine (or dynamic capability, following the definition given in Chap. 6).

venture capital funds, since VC fund managers need to liquidate their investments in a relatively short time (a few years). Selling the firm in a *trade sale* is usually quicker and far more likely than waiting for the business to become sustainable and suitable for listing the company on the stock exchange through an IPO.

## 8.4 Corporate Venturing

In corporate venturing, the focal firm acts as a venture capital fund and takes equity stakes in young technology-based companies, either directly, or by setting up an independent *corporate venture capital* arm. Investment targets for corporate venturing include startups that are developing technology of interest to the focal firm, which becomes well-positioned to become a privileged customer, distributor, or acquirer. In other cases, the focal firm may use a corporate venturing unit to manage the stakes it owns in its own corporate spin-offs. Finally, the focal firm may take stakes in firms that are developing technology or products that are complementary to the firm's core competency. This latter strategy is termed *ecosystem venturing*, and follows the rationale that, by supporting the growth of these companies, demand for the focal firm's products will increase.[13]

From the perspective of the focal firm, corporate venturing allows to create a portfolio of promising technologies and "let them grow freely in its backyard". An outright acquisition would be financially riskier, and the need to integrate the acquired companies could hinder the technology development process. Corporate venturing typically occurs in industries where technological change is significant and where complementary assets have an important role. Of course, firms using this approach must have good absorptive capacity and sufficiently high cash flow (Dushnitsky and Lenox 2005).

From the perspective of the investee company, having a corporate investor or a corporate venture capital fund as a shareholder can be an interesting proposition. Besides its financial interest, the focal firm will probably be quite open to do business, and having a powerful firm as investor and business partner can increase the growth prospects of a fledgling startup. However, the investee could also risk becoming a captive supplier to the focal firm, thus reducing the returns to its other shareholders. Therefore, firms that want to be active corporate investors must define and follow clear policies for treating investees fairly, without making an exploitative use of their dual role of shareholder and potential business partner. By failing to do so, they would risk incurring in the paradox (Dushnitsky and Shaver 2009) of being unable to close deals with the firms having the highest growth potential, or

[13]As an example, Intel, the PC microprocessor maker, has over the years made a number of investments in computer game publishers, since complex games that are demanding on computer hardware are a driver of demand for the replacement of personal computers.

being forced to pay a price premium when making the investment. At times, a corporate investor might decide to co-invest with a purely financial venture capital fund to reassure entrepreneurs of their future behavior.

## 8.5 Hiring Human Resources

A firm that lacks competencies in a given area may resort to hiring employees that already possess the underlying knowledge, either as fresh graduates from a relevant academic curriculum, or as professionals who already have some work experience in the field. Personal and corporate competencies are however not the same, since the latter derive from the integration of the former within the firm's processes and routines. One can therefore draw a parallel with corporate acquisitions and the related integration problem.

The hiring of multiple individuals has significant transaction costs, which can ultimately be comparable to those required to acquire a company of the same size. The hiring process includes searching for candidates, performing due diligence, interviewing them and negotiating employment contracts. Moreover, just like an acquiring firm has to perform a complex integration process of the target company, a hiring firm must carry out multiple and small integration processes to fully exploit the knowledge of its new employees. This is by no means an easy task, since managers will have to spread their attention to all new recruits, taking care that the way with which they enter the organization strikes the right balance between conforming to established norms and procedures, at the same time effectively introducing those elements of novelty that justified their hiring in the first place.[14] Moreover, while an acquired firm usually continues its operations throughout the integration process, the productivity of new hires is usually low, until their integration is completed.

Compared to an acquisition, hiring generally entails a smaller risk of running in the "winner's curse", since job markets are usually more liquid than the market for companies, and this makes it easier to identify a going price for a professional with given skills. However, this might not be true in the case of competencies that are just emerging. The scarcity of experts might allow them to command very high salaries, at least in the short-term, and until more people gain these skills and rebalance the job market. In any case, the hiring process is always quite risky, since it will be difficult for an employer to foresee the true value of a new employee. A person may have been an excellent performer in a previous firm, but the different

[14] Trying to integrate human resources with competencies that are significantly different from the ones that already exist in the organization is generally quite difficult. Management must explicitly support the change and make the use of these competencies mandatory in projects. If they fail to do so, organizational inertia will make it very difficult for a new employee to change established routines with her new knowledge. Social pressure will tend to make her conform to the old routines, effectively making the hiring useless from a strategic perspective.

set of complementary resources and routines and the different corporate culture will not necessarily lead to the same value when joining a new firm. Academics would say that individual performance is *institutionally specific* (Toole and Czarnitzki 2009).

## 8.6 Non-equity Strategic Alliances

A second family of methods for gaining access to competencies is involved with creating links with external entities, thus accepting to give up part of the appropriability of the related economic value. The basic way to do so is to create a *strategic alliance* with another firm, and pursue a joint program of activities, which may include R&D and product development. Alliances can create value when participating firms have complementary competencies and also when competitors cooperate in order to pursue economies of scale and/or to define common standards.[15] Recent research also suggests (Hoang and Rothaermel 2010) that successful alliances usually have the objective of exploiting existing knowledge assets and exploring their potential synergies, rather than for outright exploration of new fields in which participating entities have no prior background.

For classification purposes, under the term alliance we will only consider "non-equity" relationships that are based on contracts, which do not imply the exchange of shareholdings and/or the starting of a joint venture (which will be the subject of the next section).

When firms are bound by contractual and not institutional links, the outcome of the relationship will depend on the strength that the contract has in specifying and directing the actions to be taken by each party. Unfortunately, contracts are known by economists to be *incomplete* and *difficult to enforce*[16] and this provides room for opportunistic behavior and *free riding**,[17] thus leading to poor results. In practice,

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[15]For instance, in the late '90s, a group of competing mobile phone makers decided to develop a common operating system for next-generation smartphones. They therefore joined forces among themselves and with Psion, a maker of handheld computers, who contributed with its competencies in software.

[16]Regardless of the effort spent by managers and by their legal teams, no contract will be able to contemplate all the possible circumstances that might occur, and the eventual emergence of unforeseen events will give leeway for the parties to act opportunistically. Moreover, if a party does not fulfill contractual obligations, the other party can only start legal action and ask a court to restore its rights. However, this usually is an expensive and lengthy procedure with an uncertain outcome. Even if a court should decide in favor of the claimant, it is likely that damages paid will not be able to compensate for the broken relationship and the related opportunity costs. The greater is unenforceability, the more room is created for opportunistic behavior.

[17]Free-riding means that one party exerts less effort than it should, in the expectation that some other party will compensate for this behavior. The greater the number of participants, the greater will be the incentive to free-ride and—therefore—the likelihood that it might occur. Alternatively, a party may fear that other parties want to free-ride and will wait for a sign of commitment before

the opportunistic behavior may sometimes come from a managerial decision not to allocate the required resources to the common projects that make up the alliance. In other cases, top management may have allocated resources, but failed to fully motivate the middle managers and the employees involved, explaining the importance of the alliance projects and providing adequate incentives. When an employee is pressured and must choose whether to work on an internal project or on an alliance-related one, it will then be likely that he will opt for the former. This is especially true if work on alliance projects involves unusual organizational responsibilities, frequent or extended trips abroad, etc. A further element that might restrain participating entities from fully committing to the alliance is the risk of exposing valuable intellectual property to the other firms. This might happen when running the common project (e.g., think of one company trying to convince a competitor-alliance partner to use one of its proprietary technologies in the common project, and having to expose some critical elements to justify this choice), or as an unwanted and unrelated side effect (e.g., a representative from a competitor that is visiting for a joint meeting might overhear a discussion at the company canteen during lunchtime).

Given the complexity of alliance management, it comes as an obvious conclusion that purely formal mechanisms based on written contracts will not be able to fully allow the successful unfolding of activities. Relational mechanisms and cultural norms will therefore be needed to compensate for this (Hoetker and Mellewigt 2009).

## 8.7 Equity-Based Alliances and Joint Ventures

Equity-based alliances and joint ventures have similar objectives to non-equity alliances, but are based on a deeper institutional linkage between participating entities. These entities may exchange shareholdings directly or—more commonly—in an alliance-specific *joint venture*. At least in principle, the institutional nature of the linkage creates less ambiguity than a purely contractual one. Co-ownership of the joint venture defines an incentive to pursue its success and—should this not be strong enough for the partnering institutions—the incentive should work at least for the management team and the employees who are assigned to the venture. Moreover, in case of unforeseen circumstances and disagreements over each partner's duties, the governance structure of the joint venture can become an important mediator, attempting to solve disputes before having to take legal action. These advantages over purely contractual alliances might however not be fully achieved if the partnering institutions are very different in size and if they tend to take an intrusive role in the joint venture's governance.

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(Footnote 17 continued)

actually fully committing itself. Of course, if each party behaves in this same way, activities will never fully start.

Benefits of a joint venture must also be balanced against its drawbacks. The first one is related to the cost of establishing and maintaining a new legal entity, which requires separate accounting, a board of directors, dedicated management, and so on. These fixed costs will discourage from recurring to this solution, if not for projects of significant current or prospective value. From the organizational perspective, the personnel that are assigned to the joint venture or are directly hired by it are no longer detached members of the parent organizations. This means that both formal and informal knowledge transfer from the participating firms to the joint venture and vice versa will be quite hard to achieve. As a consequence, the joint venture will tend to lose access to potentially valuable competencies that reside in its parent companies, while it will not be easy for the same parent companies to absorb competencies generated by the joint venture.

## 8.8 Co-development

Co-development often occurs when a company needs to develop components that require highly specific competencies but does not wish—or is unable—to build these competencies in-house, and therefore has to ask a supplier. In this context, specificity means that these competencies and the ensuing products will be of little or no value, if offered to competitors of the customer company.[18]

In principle, a basic solution to this problem could consist in asking the supplier to make an investment $I$ in an R&D project, and then promising to pay a comprehensive unit price, $P$, based on expected volume, $V$, variable production cost, $VPC$, and an acceptable contribution margin $MC$. This price $P$ would obviously amount to $P = (VPC + I/V)(1 + MC)$. However, this *revenue sharing* co-development arrangement would probably not be accepted by the supplier, since multiple risks would fall on his shoulders. The first source of uncertainty is *technological* (or *development*) *risk*. The project, which ultimately comes from the customer's highly specific wishes and is not based on established competencies, may in fact not lead to the expected results. A second element of uncertainty is *market risk*, since sales volume of the end item the component will be part of, may be less than the expected value $V$. The supplier obviously has little control over $V$ (which will probably depend on many factors other than the quality of the component) and might not have enough market knowledge to assess whether $V$ is a reasonable or an overly optimistic forecast.

In principle, these risks could be attenuated with contractual clauses granting minimum volume purchases, and/or adjustments to $P$ depending on volume. However, the supplier would still incur the much greater risk of *post-contractual*

[18]This specificity can come from peculiar technological choices, from the desire to serve a particular market niche, or from the fact that the technology is just emerging and competitors have not yet shown interest in it.

*hold-up*. Since the new competencies are specific to the customer and cannot be used to supply other firms, the investment $I$ is a sunk cost. This creates a very strong incentive for the customer to wait until the project is ended and then renegotiate the terms of the contract, asking the supplier to decrease the price, theoretically all the way to $P' \cong VPC$, and regardless of volume $V$. At this point, the supplier would have no alternative but accept or go to court, which would entail a score of other costs and risks.[19]

Due to these risks and to the likelihood of post-contractual hold-up, the parties may define a co-development agreement based on *investment sharing*. The customer would then finance the development work by paying the investment $I$ up front and, since the supplier now bears no more risk, price will be set close to marginal cost $P' \cong VPC$. Such an agreement will usually grant the customer exclusive rights to the competencies generated, including ownership of, or exclusive licensing rights to, any intellectual property that might be developed under the project it has financed. This will prevent the supplier from trying to use these competencies to serve other customers that might eventually show some interest.

An investment sharing co-development agreement is not without risks, however. The customer may have problems monitoring the development work being performed by the supplier, as in a typical *principal-agent**[20] situation. For instance, the supplier might not use the financing exclusively for the project, or might try to steer its technical contents toward objectives that fit with its own strategy, rather than the customer's. Furthermore, the appropriability of the competencies will be weak, since the effective owner will be the supplier, who will gain higher bargaining power, especially if the exclusivity clauses mentioned above are difficult to enforce. The customer might therefore decide to enter an *innovation sharing* co-development agreement, and also share part of the R&D work with the supplier.

Following Bhaskaran and Krishnan (2009), the suitability of the three co-development alternatives essentially depends on the type of innovation and the major source of uncertainty (Fig. 8.5).

In the case of incremental and competence enhancing innovations, and if the main source of uncertainty is technical, the supplier will probably be in the position to make a sound assessment of risks, and accept the basic revenue sharing contract. Conversely, if uncertainty has to do with marketing and timing, an investment sharing agreement will relieve the supplier of those risks that it has no way of assessing and controlling. In the case of radical and competence destroying innovations, investment sharing might still be used if the main source of uncertainty is related to the market. Instead, if uncertainty is also related to translating the technology into a product, an innovation sharing agreement may prove to be beneficial, since it will allow the two entities to work together in overcoming technical

[19]In some industries, a supplier would not even dare sue a customer over a supply contract, in fear of losing future contracts with the same counterpart, as well as with other customers.

[20]In economics, a principal-agent problem occurs when a principal asks an agent to perform an activity, but the decisions taken by the latter might be self-interested and therefore not aligned to the interest of the former.

| Major source of uncertainty / Innovation type | Uncertainty in translating R&D to a product | Uncertainty in translating R&D and on timing | Uncertainty on timing |
|---|---|---|---|
| New to the world | Innovation sharing | Innovation sharing or investment sharing | Investment Sharing |
| Incremental | Revenue sharing | Revenue sharing or Investment sharing | Investment Sharing |

**Fig. 8.5** Choosing among the different types of co-development

difficulties, and at the same time allow the alignment of their incentives and limit the principal-agent issue.

## 8.9 Open Innovation

Open Innovation can be viewed as an "umbrella" term that encompasses a number of approaches for accessing and developing competencies by looking outside the boundaries of the firm and its immediate surroundings. The term has been made popular by Chesbrough's seminal work (2003), which identified an emerging practice by a number of large corporations, among which Procter and Gamble probably is the best known example.

Large firms traditionally ran their development activities as "closed funnels" (side a of Fig. 8.6). They would start many R&D projects to build a technological base, only a minority of which would actually lead to products with some market return. To increase productivity of their R&D expenditure, firms embracing Open Innovation realized that substantial resources were being spent on reproducing competencies and/or results that already existed in the world and—at the same time—they were not able to find alternative applications for "lost" projects that did not have a clear internal exploitation path in the firm's existing markets. Therefore, they decided that a given percentage of their R&D budgets had to be spent on projects run with external entities, or to acquire technology that had already been developed by other parties. Furthermore, R&D entities were directed to find revenues from lost projects by using licensing or spin-offs, or to use them strategically to enter new markets. The resulting "open funnel" model is shown on side b of Fig. 8.6.

This approach to managing competencies requires adequate business intelligence tools to scout for competencies and technologies, and routines and processes enabling an efficient engagement with external entities. Among the most common candidate entities, firms can consider:

- **Competitors' R&D units**. Competitors might accept an offer to cooperate on specific projects, to profit from temporarily unused capacity, or to increase returns from competencies they have developed. While a competitor might be

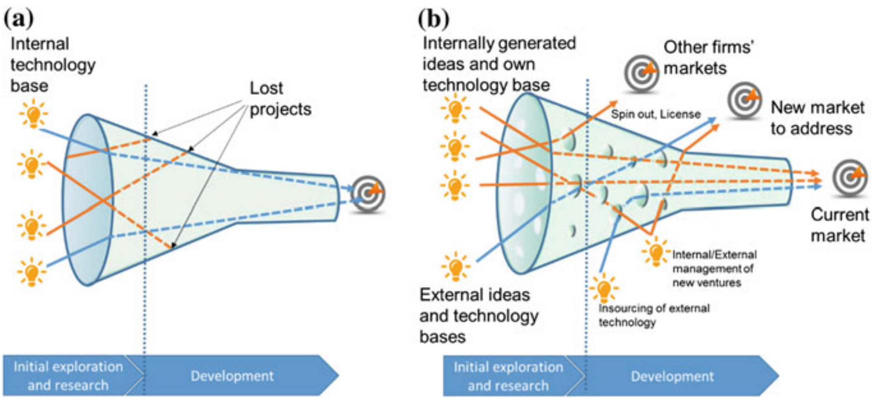


**Fig. 8.6** The traditional (*closed funnel*) approach to innovation, compared to the Open Innovation (*open funnel*) approach

willing to provide technical results, it is highly unlikely that it will accept to transfer competencies and know-how.

- **For-profit R&D firms**. In a number of industries, it is possible to identify firms whose main business is to perform outsourced R&D activity by leveraging on low cost or specific competencies. The business term for addressing these firms varies by industry. The pharmaceutical industry refers to Contract Research Organizations, while other industries may use the term Engineering Services Providers. In this case too, suppliers will be unlikely to allow an actual transfer of competencies and knowledge, and will limit themselves to delivering contractually specified results.
- **Universities and non-profit R&D organizations**. As already mentioned in Chap. 1, academic entities have a key knowledge-generating role in the innovation process. Therefore, they are interesting candidates to be engaged in the context of Open Innovation strategies, especially when dealing with competencies and activities that are related to the upstream phases of the innovation process. Universities often call this process *technology transfer**, which can lead to a number of approaches for cooperation with industry, including licensing of intellectual property, performing contract-based research and undertaking government-funded research projects jointly with firms. Moreover, academic organizations may foster the creation of *academic spinoffs** based on internally developed technology or know-how, with the purpose of facilitating relationships with industry.

  Cooperation with universities can be an attractive proposition for corporations because of the high level of their competencies, and because academic organizations are not usually as keen on preserving their proprietary know-how as for-profit firms are. In case contract-based research may lead to patents, the firm that provides finance to the project will usually gain ownership to the patent, or at least exclusive licensing rights. Moreover, it also may be relatively easy to transfer tacit knowledge, since the firm can easily hire junior academic staff, such as Ph.D. students, that have been involved in the research project. Moreover, the firm may negotiate the *secondment* of some of its own R&D personnel, who may stay with the academic lab throughout the project.

Partnering with universities is however not exempt from problems. One first issue is related to the organizational fragmentation of universities around departments and academic disciplines, which contrasts with the multidisciplinary nature of industrial problems. Moreover, universities and companies operate at somewhat different timescales and with differing objectives. A university lecturer will divide her time between a host of research projects, teaching activities, and administrative duties. Moreover, she will usually focus her efforts to achieve research results that are publishable, which usually implies a development stage that is significantly earlier than the results that a firm would expect. To avoid this potential mismatch, firms and universities nowadays tend to forge medium-long term agreements that involve multiple departments (sometimes called *University Technology Partnerships*), thus allowing interdisciplinary work and allowing a longer time frame to accommodate these different objectives. Some universities may also move to a matrix-like organization, setting up interdisciplinary and temporary *research centers,* which draw scientists coming from departments around a common problem relevant to industry. Furthermore, to make dialogue with industry easier, they can set up *Technology Transfer Offices* staffed by professional and not academic personnel.

Another issue in university partnerships is related to the confidentiality of results. As mentioned, academic researchers tend to disseminate the knowledge they generate through teaching and publishing. Publishing in important journals and being highly cited by their colleagues is—as a matter of fact—the main avenue for achieving promotion. Firms must therefore make sure that the researchers they finance do not inadvertently publish important elements of knowledge that might leak to competitors, or preempt patenting activity. Cooperation contracts usually specify that manuscripts have to be signed off by the firm before submission to journals and conferences, but enforcement of these clauses is not always easy.[21]

Given the inconveniences that firms might experiment in attempting direct interaction with universities, a number of countries have promoted applied research centers, such as the well-known Fraunhofer Society in Germany. These centers act as bridging institutions between academia and industry, with a strong focus on applied research and industrial problem solving, engaging their own staff together with academic personnel.

[21]Confidentiality clauses in industry-sponsored research also raise a number of issues related to ethics and public welfare. Firms are likely to allow dissemination of research leading to positive results, but to deny it in case of negative ones. Aside from ethical issues, it may be socially inefficient not to warn other researchers that a given solution does not work.

- **Small firms and individual inventors**. Many inventions and technologies are developed by small firms, who are often unable or unwilling to fully exploit it. The same holds for individuals who have developed specific competencies or inventions and are not in a position to create a business around them. A firm that is interested in a given technology may therefore find it quite easy and inexpensive to cooperate with the original inventor, rather than to try to replicate it internally.

Open Innovation appears to be a very attractive concept, allowing firms to tap into the possibly unlimited richness of talent and ingenuity that can be found in the world. However, the main problem is connected to the transaction costs a firm seeking for a solution will encounter in finding the right “solver” and creating an agreement that will be attractive for both parties.

A number of mechanisms for Open Innovation have emerged over the years. Following Pisano and Verganti (2008), they can be classified according to two axes. The first is the openness of the system, which can range from closed invitation-based mechanisms, which require ex-ante knowledge of potential solvers, to open mechanisms where virtually any potential solver is free to apply, and which require the capability to screen and select them ex-post. The second axis is the governance mechanism, which can range from strictly hierarchical (i.e., the seeker firm decides which solution is preferable) to flat, in which decision-making is shared between the seeker firm and the group of solvers. The former requires a well-defined innovation strategy while, in the latter, the firm uses the community not only as a source of competencies, but also as a contributor for defining innovation strategy. Table 8.1 shows the resulting four categories of Open Innovation systems.

*Crowdsourcing** marketplaces are a special type of the “innovation mall” model, and are becoming quite popular for implementing Open Innovation strategies. With crowdsourcing, problems and challenges are posted on dedicated internet marketplaces, and prizes and/or grants are awarded to the solvers that come up with the best solutions or demonstrate they have the best competencies for solving them. Well-known examples of such services are Innocentive, originally developed by the

**Table 8.1** Four different types of Open Innovation interaction models

| Governance participation | Hierarchical | Flat |
|---|---|---|
| Open | *Innovation mall*—anyone can participate, but the seeker firm decides the winner (e.g., crowdsourcing marketplaces) | *Innovation community*—anyone can propose solutions and the community decides on the winners (e.g., Open Source software projects) |
| Close | *Elite circle*—the seeker firm invites participants and decides the winner (e.g., firms in the furniture and household goods industry with designers) | *Consortium*—the seeker firm invites participants and shares technical decisions with them (industry consortia) |

pharmaceutical company Eli Lilly and that now acts for many other players in the same industry, and Ninesigma, that works on many other industries, from aerospace to consumer products.

From an economic perspective (Boudreau et al. 2011), crowdsourcing works as a "contest", in which many actors respond and only one of them wins. So, a trade-off must be found between the investment required to respond to the challenge, the size of the prize, and the probability of winning it, which depends on the number and qualification of competitors. If a participant expects a high number of competitors, he may not find a strong enough incentive to invest time and effort to come up with a strong bid, and will therefore apply only for those problems for which a solution has already been developed, or is close to being so. For this reason, innovation contests are often operated in stages. The initial challenge has the objective of qualifying the best solvers, and does not require candidates to make substantial investment to place a bid. Once these candidates have been identified, further developments will be run through a contest run among a small pool of competitors, sometimes with a small financial contribution.

Within the context of Open Innovation, firms can also decide to license other firms' intellectual property to get a foothold in a technological area of their interest, and progressively start developing competencies around it. Many patents can be targeted for this purpose, since they are essentially unused either in absolute terms, or in specific regional or industrial areas. In the case of large firms, the patent might not have been exploited because it is related to a non-core market, or because the firm made a decision to pursue different technologies. Large firms, such as IBM, often market their intellectual property quite actively, sometimes allowing very easy access to small firms and startups. Universities and research centers too might have portfolios with inactive patents, since this kind of organization cannot directly exploit inventions and must rely on licenses to do so. Therefore, it is quite common for academic institutions to file patent applications without a clear exploitation strategy, which creates an interesting opportunity for potential licensees. Finally, SMEs might be financially or organizationally constrained to fully exploit their IP and be quite happy to derive some additional revenue from it.

## 8.10 Complete Outsourcing

In this context, complete outsourcing means that the firm recognizes that a given technological area is non-core, and therefore gives up any further attempt to develop it either internally or through partnerships. From this moment on, the outcomes of this technology will be seen as "black box" components to the firm's products, and the firm will limit itself to specifying its needs, negotiating purchasing agreements, and checking compliance with specifications.

In doing so, the firm may accept "off the shelf" technology and components, which will not enable any sort of differentiation with respect to competitors. Should the firm wish to differentiate itself, the only way would be to enter a co-development agreement with the supplier and finance a firm-specific project under the provision of exclusivity.

Complete outsourcing may lead to issues and problems that usually become visible only after some time. When a firm decides to disengage from development in a given technological area, it progressively disperses its competencies. At first, some of the employees that were working in that area with technical responsibilities may be given purchasing roles, and will obviously become very attentive and technically capable buyers. As the years go by, these employees either migrate to other functions or retire, and the firm will substitute them with personnel that does not have the same technical expertise and understanding of the technology. It therefore can become difficult for the company to effectively specify, buy and verify the components it needs.

Moreover, when all competitors in an industry share the same decision of outsourcing a given technology or component, this might lead to the emergence of monopolistic suppliers. Should this happen, the industry bears the risk that this supplier will become complacent and stop innovating, thus damaging the prospects for its customers. This is often at the origin of many trend reversals in industry, which often oscillates between outsourcing and vertical integration choices.[22]

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[22]For instance, a number of medium-high end Swiss watch manufacturers have recently reversed the trend of buying mechanisms from specialist suppliers and started developing and producing them in-house, as was done by the traditional “manufactures”, in order to avoid the commoditization of their products.

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# Chapter 9
# Innovation Strategy as Project Portfolio Management

This chapter provides a complementary view of innovation strategy to the one that has been developed in Chap. 8. Still following the resource-based view of the firm, we will concentrate on the decisions pertaining to which projects and activities should be performed, given the competencies the firm currently possesses, and the ones that it wishes to develop. Most activities related to innovation are project-based, and it is therefore possible to borrow concepts, methods, and tools from the field of *Project Portfolio Management**, or PPM.[1]

## 9.1 Project Portfolio Management in Perspective

PPM is one of the areas of the broader discipline of Project Management, and focuses on the selection of the projects that must be initiated, managed, and terminated, for the purpose of achieving the objectives of the organization. Tools used in PPM are a relatively recent addition to the toolbox of practicing managers. The recent success of PPM is due to the recognition of its strategic relevance, and to the diffusion of IT-based tools that make it easier to collect and represent information on multiple projects.

Due to its strategic relevance, firms that do not make a correct use of PPM run the risk of being unable of formulating and enacting a sound innovation strategy. In general, lack of discipline in PPM leads firms to start too many R&D projects, without a clear strategic focus and/or without a strong understanding of their compatibility with the type and quantity of available resources. It is always fairly easy to give a go-ahead to a potentially interesting project, but attention should be

[1]Project Portfolio Management is a key area of the Project Management literature. This literature historically has had a bottom up approach at projects. *Project management stricto* sensu deals with individual projects at operational level, while *program management* deals with programs, or clusters of related projects, at a tactical level. Finally, *project portfolio management* copes with the strategic decision on which projects and programs should be initiated. In the context of innovation management, one can assume a top-down approach in which the firm must first decide what to do ("doing the right things"), and then focuses on execution ("doing things right").



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_9

paid to the strategic reasons that justify it (which, in turn, determine what specific outcomes should be expected from it) and on the resources that are required in order to ensure success with respect to timing and results.

It is not uncommon for companies to be quite unaware of their R&D portfolio. Examples of this inability are not knowing how many and which R&D projects are active at a given time, being uninformed of the ratio between the overall workload and the available manpower (which often turns out to be greater than 100 %), and assigning personnel to an excessively high number of simultaneous projects. The immediate outcome of not having enough resources assigned to projects, and allowing them to work inefficiently, is that projects are doomed to be delayed. When this happens, project managers will scramble to get hold of more resources, thus initiating a highly political wrangle, with endless meetings and backdoor dealings, which leads to high influence costs and even greater inefficiency.

A firm that does not use PPM correctly will also find it difficult to terminate unsuccessful projects when it becomes clear that the desired results are not emerging, and to do so before costs become too high. When dealing with R&D and innovation, not being able to terminate projects is a big problem. It means either that the firm is unable to manage its project portfolio and keeps on running unsuccessful projects or—conversely—that its innovation strategy is so conservative that it concentrates on projects whose probability of success is close to one. Keeping bad projects alive also deprives good projects from accessing resources and achieving their potential results.

Not having a sufficiently developed PPM system, firms will also find it difficult to explicitly relate projects to innovation strategy. As a first result, the selection process will be weak and highly subject to emotion, political influence, and cognitive bias (Hammond et al. 2002). Furthermore, if projects have fuzzy objectives, they will likely be overloaded with incoherent goals. For instance, one may start a customization project, characterized by a limited budget and requiring a quick completion time, and hastily accept a supplier's proposal to experiment with a new technical solution at the same time. The likely outcome will be ending up with a failed project, missing both objectives.

Formulating and executing an innovation strategy therefore requires a robust PPM system, which can be conceived as being based on three pillars. These three pillars will be discussed in the following sections and are categorizing projects, defining a process for evaluating projects, and using tools for decision making.

## 9.2 Categorizing Projects and Defining Roadmaps

When dealing with R&D and innovation activities, the first element to be recognized is that projects are not all the same. These differences should be managed through an appropriate categorization, thus avoiding comparisons between projects of a completely different nature. These differences can be identified along a number of dimensions, such as risk, project size, and project scope. Concerning the latter, projects may be characterized by different degrees of innovative content with respect to the product (or specific subsystems), the process, etc. However, the main difference to be identified is related to distance that the project's results will have from the market. As a first cut, it is certainly possible to set research projects aside from development projects. However, one can develop finer differences, as in the following list.

- **Basic research projects**. The aim of basic research projects is to develop knowledge in a given technological domain, generally without having identified a clearly defined application yet. In profit-making firms, projects of this kind are not very common, but are not impossible to find. A firm may pursue them because it considers the knowledge that could be generated useful for either building further developments, or for increasing its absorptive capacity.
- **Applied research and technology development projects**. The aim of an applied research project is to generate knowledge, and/or to develop and demonstrate the suitability of a given technology in solving a problem that is related to the business. The result usually consists of a demonstrator, and is not yet directly applicable to the firm's products and processes, since the validation performed is related to the technology per se, without having fully worked on its integration with other subsystems that would make up a real product.[2]

When dealing with basic or applied research projects, Scholefield (1993) suggested a classification that is associated to the objectives of research projects. On the one side, one can have "maintenance" R&D objectives, with the purpose of ensuring the survival of the firm and keeping up its competitive advantage. Conversely, one can have "growth" R&D objectives, aimed at upgrading the firm's competencies by mastering a new technology or looking for technological breakthroughs.

Concerning development projects, one can use the following classification:

- **Next-generation and/or platform development projects**. In this kind of project, the focus is not on a technology, but on the integration of different technologies and solutions in order to create the foundation for future products, processes and services. The result usually is a prototype which engineers can rely on, in order to proceed with a product development project that will lead to a commercial launch. Alternatively, the result can be a *platform*, defined as "a collection of technological assets that are proven to work together", and that might serve as the basis for developing a *family* of multiple *derivative products*.

[2]When operating in industry, the concepts of basic and applied research must be related to the specific firm, and do not necessarily imply activities that have a high scientific or inventive profile, or that generate leading edge technology. For instance, a motorcycle manufacturer experimenting and testing a new commercially available component, such as LED headlights, is carrying out what can be considered to be applied research. In fact, this activity is aimed at creating knowledge ("Let's try fitting these newfangled LED headlights on a couple of our bikes and see if they work"), and is not yet directed to a specific product (in which case the objective would be "Let's design our next bike with LED headlights").

- **Product development projects**. These projects aim at launching a specific product addressed to a given market segment. Depending on the existence or not of a prior platform development, a product development project can be a more or less complex activity.
- **Customization projects**. Finally, customization projects have the objective of adapting an existing product to the needs of a specific customer (e.g., "this delivery company wants a special version of our vans for its fleet") or market niche (e.g., "a version of car model X, adapted to the specific regulations in force in country Y").

### *9.2.1 Platform Product Development*

The platform concept has become a key element of innovation strategy (Meyer and Lehnerd 1997). Platform-based product development consists in structuring the product development pipeline in a two-tier structure. Platform projects establish a technological basis that, until obsolete, allows the firm to come up with a set of smaller (in terms of cost and development time) derivative development projects.[3] This strategy exhibits a number of advantages (Cantamessa 2005).

One first advantage is the potential sharing of components among product versions, which can lead to significant economies of scale in manufacturing and purchasing. Furthermore, a properly configured platform strategy allows the overall development cost of the platform projects and of its derivatives to be less than what would have been spent with an equivalent number of independent projects. Moreover, since the duration of derivative projects is short, this allows a quick reaction to changes in the market. As a final and very important advantage, a platform-based product development strategy tends to keep more innovative activities apart from the less innovative ones. As shown in Fig. 9.1, platform projects are used to transfer results from research and technology development into product development. This approach gives research projects a clear objective ("we must finish project X by month K, so to feed its results into platform project Y"). It also allows the testing of new and risky technologies in the context of a large-scale project that—not being directly connected to a product launch—is not generally subject to an exceedingly tight schedule. Platform projects can therefore be used to validate a set of new technologies—individually and with respect to their interoperability—and to create the know-how needed to deploy them into derivative

[3]In quantitative terms, a firm may define the degree with which derivatives are to be dependent on the platform by expressing the percentages of components (in number or in value) that must be common and based on the platform, contrasted to the ones that can be specific to each derivate product. Similarly, the degree of innovation of each platform with respect to its predecessor can be represented by the percentage of new components (again, in number or value), contrasted to the ones that are to be *carried over* from previous ones.

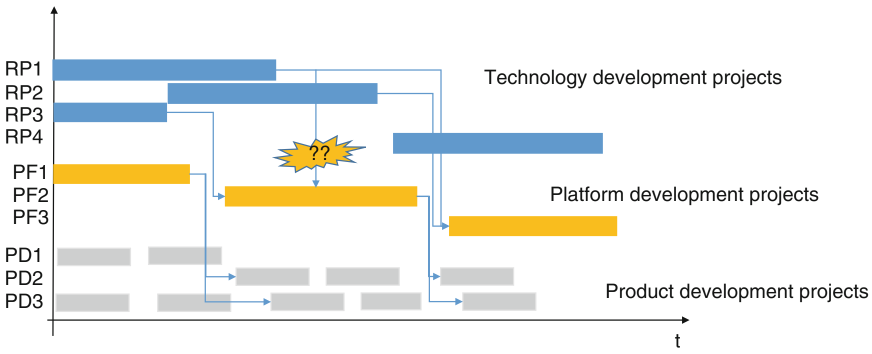


**Fig. 9.1** The role of platform development projects in innovation strategy

product development. At the same time, by taking the more innovative design tasks out of derivative product development, engineers are discouraged from over-designing individual products ("why don't we try technology X in this new product Z?"), which generally leads to increased cost and lead time, and often with dubious benefits. For instance, Fig. 9.1 shows one incoherent proposal of "inserting" a new technology in the midst of platform development project.

Platform-based product development also has a few risks and drawbacks. Aside from the greater complexity in the portfolio management process, the firm may mismanage the strategy and end up with higher overall development costs. Moreover, it may be forced to delay the launch of new products until the platform project is ended, or find itself locked in the platform's technology for a long time. Finally, component sharing is known to be a double-edged sword (Krishnan and Gupta 2001). If not carefully planned, it may lead to insufficient differentiation between products and therefore lead to loss of market share. Due to the importance of the subject, Chap. 16 will explore the issue in depth and propose a number of practical approaches for a sound definition of platforms and product families.

### *9.2.2 Technology Roadmapping*

The idea behind technology roadmapping is to create a high-level view of the set of projects of different types that the firm is considering as candidates for its portfolio, together with their mutual relationships and their placement in time. In general, a *technology roadmap** provides a comprehensive view of the project portfolio in order to ensure its intrinsic coherence, and does not cope with its economic or financial sustainability. A technology roadmap allows having a compact view of the portfolio and of the way with which results from "upstream" activities will feed into "downstream" projects. In general, the following elements will be included:

- **Triggers**. Triggers are events that are exogenous but relevant to the innovation strategy of the firm. Examples of triggers are the time at which a governmental policy or a standard comes in force, the release of a new technology by a key vendor, etc.
- **Markets**. The market section of a technology roadmap depicts the markets in which the company wishes to operate and the timing of entry and exit.
- **Products**. The product section represents the timeline of development and introduction of individual products in the markets identified above. The relationship between products and markets can be simple, with each product being related to a single market. However, it can also be defined by a matrix, with each product being sold in different markets or market segments.
- **Platforms**. In case products are organized in product families related to platforms, this section represents the development of the platforms themselves.
- **Technology**. This section represents the development of individual technologies that the firm considers to be enabling and relevant with respect to the downstream development of platforms and products.
- **Capabilities**. Finally, this section represents the projects used to build the competencies that are needed in order to sustain the downstream R&D activity.

A fictitious example of technology roadmap is shown in the following Fig. 9.2. The graphical layout of this roadmap is based on layers, with development work being represented in gray and sales in blue or red. Depending on the case—alternative layouts can be used, such as trees, flowcharts, etc.

The coherence of the technology roadmap can be studied by progressing top-down, from left to right, following a “technology-push” approach, which shows the way and the timing with which upstream results can be used by downstream activities. Conversely, one can move bottom-up, from right to left, following a “demand-pull” perspective. This implies checking that needs that emerge from the market are appropriately addressed by the upstream activities and at the right time.

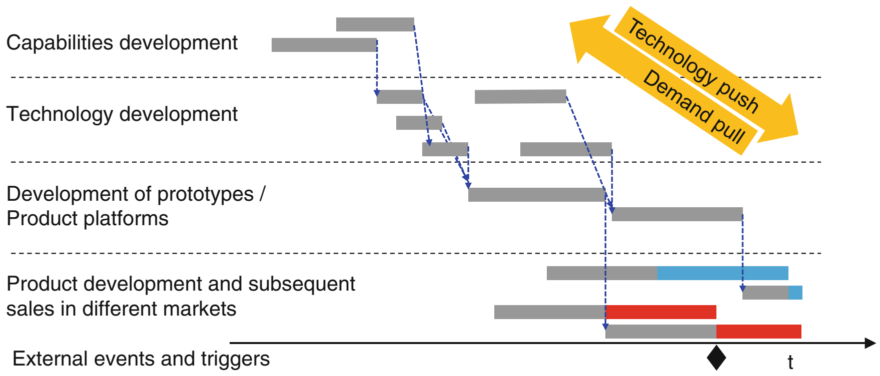


**Fig. 9.2** Example of a technology roadmap

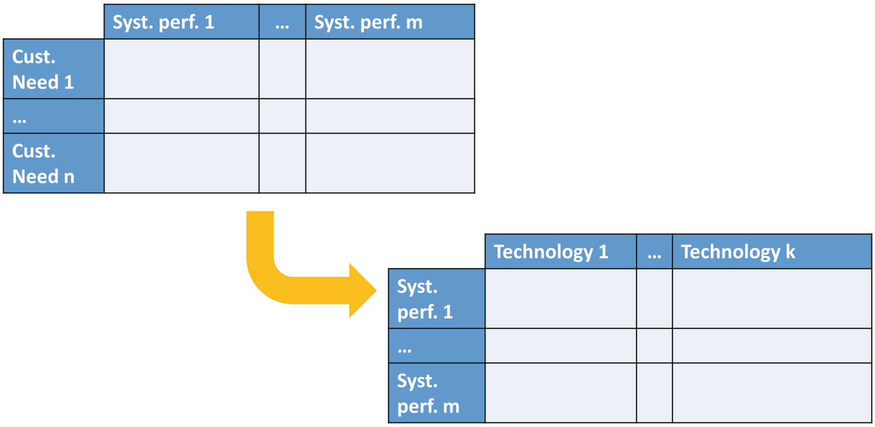


**Fig. 9.3** Using incidence matrices to align technological development to market needs

In practice, roadmapping will be carried out by iterating the two approaches and until a satisfactory proposal is reached.

For a deeper analysis, the connections between technologies, products and market needs can be studied with more sophisticated methods. In general, these methods use incidence matrices, in which features at different upstream and downstream levels are mapped onto each other in order to translate market needs into technological priorities. Figure 9.3 represents a simple example, in which future customer needs and their importance (usually coming from market research, and rated on a 1–5 scale) are at first mapped on system performance indicators through a qualitative rating of relevance where 1 implies “very weak”, 3 “weak”, and 9 “strong”. The mapping is performed through a simple mechanism of weighted sums.[4] Then, performance indicators are mapped on enabling technologies in order to prioritize them.

More elaborate methods have also been proposed, such as CFTP (or *Customer-Focused Technology Planning**, (Paap 1994), in which the analysis is enriched by operating by markets and customer segments and by adding comparisons with competitors.

[4]The approach closely resembles Quality Function Deployment, which a widely used methodology in product development (see Chap. 14 for further details). The weighted-sum mechanism is very coarse, since importance and relevance indicators are qualitative concepts, and their numerical representation is based on an ordinal, and not a cardinal, scale. Strictly speaking, ordinary algebraic operations should not be applied to this measurement system, but the approach is nonetheless commonly practiced, under the condition that outcomes are not taken as precise measures but as rough indicators, and that the number of rows and columns in the matrices is sufficiently high, thus suggesting that major errors should be “evened out”.

## 9.3 Defining a Process for Project Evaluation

All projects in an organization follow a lifecycle that goes from the initial inception, through its planning and to its execution—usually in a number of major phases—to the exploitation of its results within the organization. When the number of projects is high, firms will tend to reduce the specificity with which each project is organized and managed, and try to fit projects within a relatively stable and routinary framework. Therefore, while the contents of each project will be unique, the way with which it is structured and managed will tend to be similar to other projects, or at least to the ones belonging to the same category. It is therefore not a contradiction to state that, when dealing with R&D and innovation, projects will be subject to a relatively standardized process.

Understanding and structuring this process is strategically necessary, first of all because the firm must be able to analyze its strengths and weaknesses (Hansen and Birkinshaw 2007). For instance, a firm may excel at generating ideas for new products, but then fail in exploiting their results. Conversely, another firm may be very good when executing projects, but be quite poor in defining which projects should be pursued. Secondly, the process that represents the project lifecycle provides an important opportunity for selecting projects during their progress. In general, innovation projects exhibit a significant uncertainty with respect to technology and market risk, which makes it very difficult to make an *ex-ante* assessment of their viability. If forced to make an up-front selection, firms would probably only accept projects with very low uncertainty, but this would imply a very strong bias in favor of incremental innovation. On the opposite, firms should accept a high number of projects, but be ready to terminate them as soon as they turn out to be unproductive.

In some industries, uncertainty is so high that an *ex-ante* selection would be impossible to make. The most extreme example probably comes from the pharmaceutical industry, where it is customary (Fig. 9.4) to start from an order of magnitude of 10,000 candidate chemical compounds and make an in silico (i.e., through simulation) or in vitro (i.e., in labs) screening in order to come up with a set

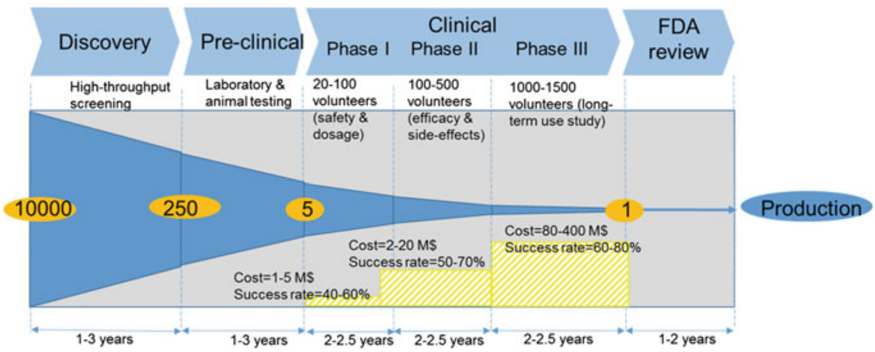


**Fig. 9.4** The development pipeline in the pharmaceutical industry (from Burrill 2009)

of 200–300 candidates. These are then tested in vivo (i.e., on animals) until a set of 5–6 candidate compounds are left. What follows are three rounds of *clinical trials* on humans, aimed at assessing safety, dosage, efficacy, short-, and long-term side effects on a progressively higher number of volunteers. At the end, the pharmaceutical company may hope to end up with one drug that can be launched on the market, so that margins from sales may cover the development cost for the entire pipeline of candidates on which the firm has worked.

Less extreme cases can be found in the automotive industry, where a firm may typically examine a dozen or so concepts, draft a few alternative specifications for the most promising ones, and then give a go-ahead for the development of a single vehicle.

Managing a pipeline—or a funnel—of projects with high individual uncertainty requires a careful understanding of the relationship between project cost and evolution of uncertainty. In fact, the economic foundation of a system in which many projects are started and progressively weeded out, and only a few make it to the market, is related to the way cost and uncertainty evolve over time (Fig. 9.5). In general, when a project progresses from its initial to its final phases, project costs escalate over time, leading to an s-curve. Hence, the initial phases of projects are not very expensive, until a given moment after which substantially greater investments are required. In the pharmaceutical industry, this generally occurs for clinical trials. In manufacturing industries, it usually coincides with the detailed design phase, which requires substantial amounts of engineering man-hours. At the same time, it is common for uncertainty on technical feasibility and market acceptance to decrease while the project progresses, generally quite quickly during the initial phases, and then more slowly. This is especially true if the later and more expensive phases are aimed at perfecting the product, rather than to making sure that it will work.

In such a situation, the early phases have a strong "lever effect", since a limited investment can lead to strong returns with respect to uncertainty reduction. In this case, firms can afford to make a preliminary investment in a high number of projects

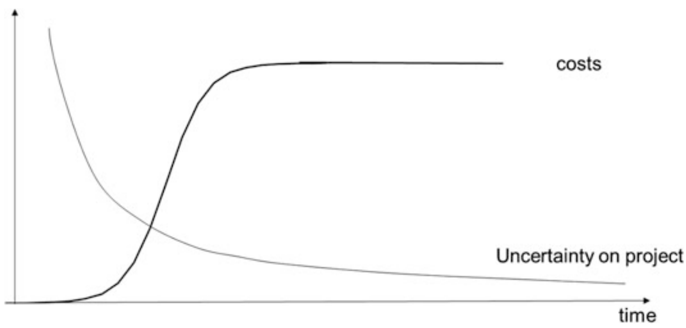


**Fig. 9.5** A typical evolution of cost and uncertainty during project evolution

who are likely to fail, since the return coming from screening the good ones outweighs the loss coming from the failed ones. Of course, the firm will have to be highly selective at the point of the s-curve where the slope of the cost curve becomes higher.

In order to formalize a procedure of this kind, Edgett and Cooper (Cooper 1990; Cooper and Edgett 1996; Cooper et al. 2002a, b, I–II) have developed the widely used concept of a *Stage-Gate*® system. In a Stage-Gate system, projects are divided in *stages*, whose deliverables are to be examined at *gates* in which continuation of the project to the next stage or termination will be decided on. In case of a continuation decision, a budget is allocated so that the project team can work on the next stage, but not beyond. At the subsequent gate a further decision will be taken, based on the new information that will be developed during the stage.

Stage-Gate systems are widely used, sometimes leading to unsatisfactory results (Schmidt et al. 2009). This may be due to a variety of reasons that have to do with the design of the system.

First, Stage-Gate systems are based on the hypothesis described in Fig. 9.5, with relatively cheap early phases that lead to a significant reduction in risk. This may not always be the case. There may be cases in which uncertainty remains very high until the very end (Montagna 2011), either because market acceptance is difficult to evaluate, or because the technology used is unstable. Similarly, the cost curve may have a different shape, with high initial outlays followed by lower costs due to small adaptations. A typical case comes from the Internet industry, in which firms make a significant investment in a software platform and then perform continuous experimentation and fine-tuning of new products, services, and solutions, until they reach the desired results.

Secondly, the Stage-Gate system must be structured in a way that is appropriate to the project category. When structuring such a system, one must balance the budget allocated to each stage with the contents of the deliverables that will be asked for at the next gate, and with an expected rejection rate. In the end, one cannot achieve more than what one spends for. If a firm requires an amount of uncertainty reduction during the early phases that is not supported by an adequate budget, there is a significant risk that potentially successful projects may be terminated. The number of stages is also important, since a low number will make the selection process ineffective, while a high number will make it excessively bureaucratic. For conservative and risk-averse firms, it may also be difficult to "shape" the system in a way that submission of projects is actively encouraged at the entrance of the funnel, and enforcing strict "go-no go" decisions in the subsequent phases, so that only a few projects make it to the end.[5]

[5]In fact, there may be a striking and difficult-to-reconcile difference between the organizational culture required by early phases, in which openness and risk-taking should be promoted, and the subsequent ones, in which correct execution and detailed analysis ought to prevail. Some firms have decided to split their Stage-Gate systems in two sections, and to assign them to different organizational units (e.g., the pharmaceutical company Eli Lilly has decided to set up a separate "discovery" organization dealing with the early phases of the innovation funnel).

Finally, the way the Stage-Gate system is run is also quite critical. The panels in charge of “go-no go” decisions must be carefully composed, with a good balance of managers and specialists, internal and external experts. Moreover, decisions must be implemented without any deviations. If news spread that a terminated project can be salvaged through internal politics, the Stage-Gate system will be viewed as a useless system adding to internal bureaucracy and that can easily be sidestepped. Finally, firms should not “bury” terminated projects, but try to extract as much knowledge as possible from them, and structure and disseminate these “lessons learned” throughout the organization.

## 9.4 Project Selection

Once a firm has defined distinct project categories and defined a process for selecting projects, there still is a key issue to be solved, which is related to the criteria and to the methods that ought to be used for performing this selection.

This problem exhibits substantial similarities to the portfolio selection problem that is found in finance, which suggests that some methods might be borrowed from this latter field. A financial portfolio manager must optimally allocate a finite fund to a number of investments in financial securities by taking investment and divestment decisions. Each security will be characterized by an inherent expected return and level of risk, with some degree of correlation existing among the securities. In a similar way, a project portfolio manager will have to take initiation and termination decisions on projects, and allocate a finite budget made up of financial, human, and physical resources among them. Projects too may be characterized by expected returns and levels of risk, and positive correlation may be present if project outcomes are complementary, while negative correlation may be due to substitute outcomes (e.g., two similar products) or to projects that compete over scarce resources.

The conceptual similarities between financial and project portfolio management should not make us neglect some substantial differences between the two fields. First, projects are not traded on the market, which means that financial valuations and investment/divestment decisions are substantially more difficult to make and execute. Moreover, the decision of buying and selling financial securities is relatively fine-grained, while initiating or terminating projects is not, and leads to a Boolean type of decision (e.g., you can easily sell 484 shares out of a 1452 holding, but a project cannot be closed down by 1/3, and will have to be either continued or terminated). Secondly, project portfolio management has a clear strategic role within the firm, and managers will righteously wish to include non-financial issues in the decision-making process, which may at times include somewhat tacit and even emotional aspects. Because of this, managers will tend to reject “black box” decision-support methods that prescriptively give solutions without providing a clear view of the underlying reasons. Conversely, managers may accept methods that help them rationalize a process they can understand and feel as their own.

### 9.4.1 Top-Down Versus Bottom-Up Selection

In general, the project portfolio selection process can be viewed as either a bottom-up process, or as a top-down one. In the bottom-up approach, projects are proposed by corporate functions and selected according to their inherent viability and compliance to strategy. In the top-down approach, strategic directions are translated into a budget allocation decision which assigns resources at first to predefined project categories and objectives (e.g., X million dollars to radical innovation projects in domain Y) and then to individual projects proposed by corporate functions. The bottom-up approach appears easier to implement, and leaves more creative freedom to the lower ranks of the organization, which are closer to the needs of business operations and to the market. At the same time, it requires very rigorous decisions and might make it difficult to implement a centrally defined strategy, should proposals coming from the bottom not go in the desired direction. Conversely, the top-down approach requires more *ex-ante* activity in the budgeting process and grants less freedom to the organization. At the same time, it makes it easier to enforce a strategy that has been defined at corporate level.

In practice, firms will always adopt some kind of hybrid between bottom-up and top-down portfolio selection. The degree with which either should prevail and the way they should be managed depends on corporate culture, but should also depend on the type of innovations the organization is trying to pursue. If, for instance, a firm is trying to enact a strategy based on radical innovations, it will need both approaches. Working bottom-up will favor the emergence of new ideas, but top-down action may be required in order to overcome organizational inertia when it comes to implementing them.

### 9.4.2 Financial Methods for Project Selection

Any innovation project involves the investment of financial resources, in the expectance of future returns, which will generally be in terms of margins from sales, in case of product innovation, or cost reductions, in case of process innovations. Therefore, project selection must take into account financial aspects, which can be evaluated according to the methods described in the following.

#### 9.4.2.1 Net Present Value

According to finance theory, the key indicator that ought to be used when assessing a project is the *Net Present Value** (NPV) of future marginal cash flows. As in (9.1), the analyst should compute the cash flows that the project would lead to (negative during the investment phase, positive when enjoying its results) and compare them to the cash flows one would have by not initiating the project. These marginal cash flows at each time period, $CF_t$, ought to be discounted according to a given interest rate $i$, since the value of future cash flows will be reduced because of their inherent uncertainty. In algebraic terms,

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{\mathrm{CF}_t}{(1+i)^t} \tag{9.1}$$

and the firm will accept projects for which NPV > 0.

This seemingly straightforward approach underlies a number of quite significant issues. The first one is related to the use of NPV itself, since many firms tend to neglect it, and use the much simpler *Payback Time** (PBT) criterion instead. Following PBT, the firm defines a maximum time for recovering investments, $T$, and will accept projects requiring an investment $I$ only if the future positive cash flows comply with this threshold. In mathematical terms, if

$$\sum_{t=0}^{T} \mathrm{CF}_t \geq I \tag{9.2}$$

From a theoretical perspective, the PBT method is inherently flawed, since it does not discount cash flows, and because it purposely neglects any event that might occur after $T$. Therefore, a project with short PBT but low long-term returns (dashed line in Fig. 9.6) will be preferred to a project with a longer PBT and substantial long-term returns (continuous line in Fig. 9.6). As such, the use of PBT leads to a strong bias toward incremental innovations.

Despite these shortcomings, many firms use PBT not only because of its simplicity, but also because of particular situations that may at least partially justify its use. In first instance, there might be cases in which cash flows beyond $T$ are irrelevant, because of technological obsolescence or rapidly changing demand. Secondly, liquidity is generally a major concern for firms, and PBT ensures a quick

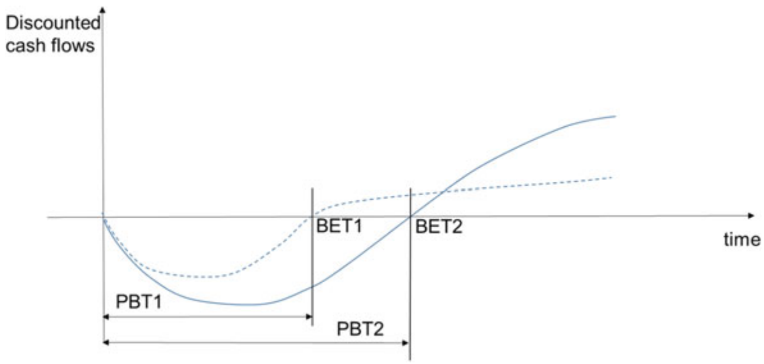


**Fig. 9.6** The bias introduced by payback time in project selection

recovery of the cash employed in projects. This is especially important when operating in very turbulent environments and the firm does not have adequate visibility of future opportunities. Committing to a number of profitable but long-term projects might be dangerous for the firm since—should a much more profitable opportunity arise midway in the progress of these projects—the necessary financial resources would be unavailable.[6]

Aside from the choice of the criterion to use, it is generally quite difficult to make a proper use of financial methods. One first issue is related to the concept of *relevant costs*. When evaluating marginal cash flows, one should not consider sunk costs, i.e., costs that have already been incurred and that would not be recovered by any of the decisions that are currently at stake. Therefore, past expenditure should never be considered when deciding on a new project, or on the continuation of an existing one. For instance, a sentence like "*we have already spent 2 million on this project, so we should consider that...*" should never accepted.

More subtle is the problem of potentially sunk costs that are associated to existing resources, human, or capital. For instance, the cost of technical personnel is often a sunk cost, since by deciding for or against the project, it may be unlikely for the firm to hire or fire anyone, and salaries will have to be paid regardless of the actual use of these resources. As a general rule, a cost associated to a resource should be included if one of the two following conditions are true; (i) the number of resources does depend on the initiation or termination of the project (e.g., if personnel can be hired or fired); (ii) the number of resources has already been set, but the number of competing projects is such that, should the project not be approved, these resources would nonetheless be saturated by alternative uses (e.g., if personnel can always be allocated to other projects). In this latter case, the cost of resources is technically "sunk", but must be considered as an opportunity cost.[7]

When considering human resources, condition (ii) is generally true, since managers usually have the problem of selecting among more projects than they can cope with. However, they should be wary of exceptions that might occur, which might lead to killing projects that would be marginally profitable, and have to pay the salaries just the same.

Besides personnel, another critical example may come from the use of highly specialized physical assets, such as laboratory equipment, test benches, and so forth. In these cases, it is very common for firms to fall into a "sunk cost trap" and charge hourly costs for the use of this equipment, derived from annual amortization

[6]In a perfect market, this would not seem to be an issue, since the firm would be able to raise new financial resources in order to deal with an emerging and highly attractive opportunity. However, it is known that perfect markets are more an abstraction than reality. In any case, even if financing means were available, it is likely that the firm would find key resources tied up in its existing portfolio of long-term projects and be unable to expand its organization efficiently in order to work on the new projects.

[7]Of course, not considering sunk costs when taking a managerial decision on the use of resources does not mean that these costs should not be taken into account for cost accounting.

rates and an expected use, and end up with not enough projects and underused resources.

Table 9.1 shows a typical example of this mistake, with a firm whose projects require specific costs, together with the use of a laboratory. The lab has an annual amortization rate equal to 1.28 M€/year and an expected usage of 1600 h/year, leading to an hourly cost rate of 800 €. The table clearly shows that there are not enough candidate projects to saturate the lab and that, by including hourly cost, the firm will mistakenly not start projects C and D, leading to lower profits and an even more underused laboratory.

It is generally quite difficult to spot these mistakes analytically or by going over accounting reports. The best approach is to walk around facilities, looking for idle resources, and asking what is happening. Quite often, these resources have been idled by a project selection process that has erroneously accounted for sunk costs associated to the original investment. In other cases, these assets should not be there, and the company should consider disposing of them. Following the case described above, the easiest way to notice the problem would be to walk to the lab, notice that it is working much below capacity (480 out of 1600 h/year) and start asking questions.

A second problem in the financial evaluation of projects is associated to the differential nature of the cash flows that should be evaluated in NPV, since the cash flows due to the project—if activated—should be compared against the cash flows that would emerge by *not* starting the project.

In general, it is not straightforward to foresee what would happen by not having the project, and it is tempting to assume that "nothing" would happen (Fig. 9.7). Such an assumption might be misleading, since the decision not to start a project could lead to the deterioration of the firm's competitive position, the loss of market share of current products, and so on, which implies progressively negative cash flows with respect to the current status.

A final issue is associated to the definition of the discount rate in NPV, which represents the risk and uncertainty that is specific to the project being evaluated. Following financial theory, one should be able to define such rate by analogy with tradable securities having similar risk profiles, using the *Capital Asset Pricing Model** method. Unfortunately, this method requires the identification of one or more firms with publicly traded shares and whose risk profile is the same as the one of the single project being considered. This is generally next to impossible, aside from particular industries such as biotech, where public companies focused on individual projects do exist. Alternatively, firms can define discount rates that are specific to project categories, following the same classification that was discussed in the previous section of this chapter. However, very few firms have sufficient knowledge to make a proper assessment of this kind. In the end, it is likely for firms to simply use the *Weighted Average Cost of Capital** (WACC), which is the average interest rate that is required by shareholders and debtholders of the firm, higher for the former, who bear more risk, and lower for the latter. In turn, this rate represents the risk that is represents the entire portfolio of activities the firm is engaged in. The use of WACC can be quite misleading, because it does not represent project-specific risk. So, using

**Table 9.1** An example of a mistaken decision due to sunk costs

| Project | Project cost (k€) | Use of lab (h) | Use of lab (k€) | Total accounting costs (k€) | Expected margins after the project ends (k€) | Accounting profits (k€) | Decision | Actual use of lab (h) | Actual profits (k€) | Profits by accepting all projects (k€) |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 100 | 200 | 160 | 260 | 300 | 40 | Y | 160 | 200 | 200 |
| B | 200 | 100 | 80 | 280 | 300 | 20 | Y | 80 | 100 | 100 |
| C | 300 | 300 | 240 | 540 | 450 | −90 | N | 0 | 0 | 150 |
| D | 400 | 400 | 320 | 720 | 600 | −120 | N | 0 | 0 | 200 |
| E | 200 | 300 | 240 | 440 | 550 | 110 | Y | 240 | 350 | 350 |
| Totals | | 1300 | 1040 | | | | | 480 | 650 | 1000 |

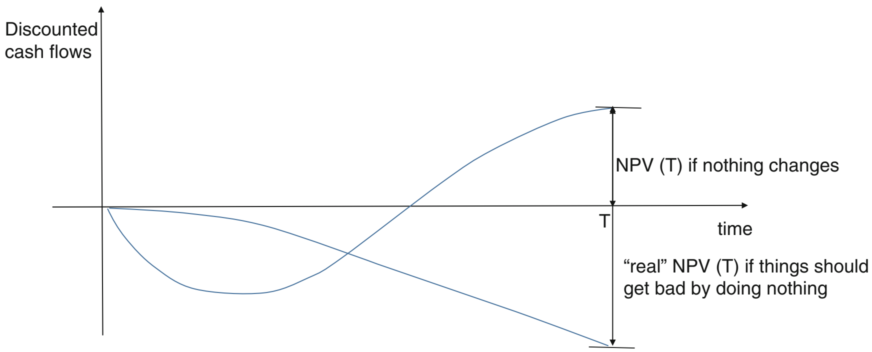


**Fig. 9.7** Comparing cash flows resulting from launching and not launching a projects

WACC will lead to a bias that favors projects that are riskier than the average, and goes against the ones that are less risky.

The complexity of computing risk-adjusted and project-specific rates of return suggests the use of simpler, albeit somewhat rougher, approaches. One such approach, termed *Expected Commercial Value** (ECV), consists in estimating project-specific technological risk, $P_t$, and commercial risk, $P_c$, separately from the interest rate, and considering the sequential nature with which these two risks manifest themselves. ECV is based on a very simple decision tree (Fig. 9.8) where DC represents costs related to technical development and CP the costs associated to production and launch. ECV can readily be computed as follows, provided expert opinion can be used to provide estimates for $P_t$ and $P_c$.

$$\mathrm{ECV} = (\mathrm{NPV} * P_C - \mathrm{CP}) * P_t - \mathrm{DC} \tag{9.3}$$

Since development activity is usually limited by a given budget, it can be interesting to select projects that do not only have a high ECV, but also provide a high level of ECV per dollar invested. This leads to the so-called Productivity Index (PI), which is often used in conjunction to ECV.

$$\mathrm{PI} = \frac{\mathrm{ECV}}{\mathrm{DC}} \tag{9.4}$$

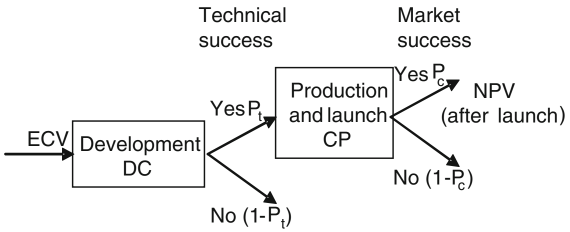


**Fig. 9.8** The decision tree representing the ECV method

#### 9.4.2.2 The Option Value of Projects

In the previous section, we discussed the opportunity of supporting project portfolio decisions with Stage and Gate processes. Even if such a process is not formalized, it is only logical for firms to consider investment in new projects on a step-by-step basis, so that further investment is decided for only if the results of previous phases are sufficiently promising.

From a financial perspective, this kind of behavior is very interesting, since decisions to fund the *i-th* stage of a project will not depend on the intrinsic returns deriving from stage $i$. Rather, the decision will be based on the consideration that—should stage $i$ be successful—the firm will be able to invest in stage $i + 1$ (something that could not be done if stage $i$ were not funded). In turn, the value of stage $i + 1$ is associated to the future possibility of operating stage $i + 2$, and so forth, until the *n-th* and final stage of the project, whose value will effectively be associated to the profits that will accrue because of the completion of the project. In financial terms, stage $i$ of a project has both an *intrinsic value*, due to the NPV of the cash flows it will generate independently, and an *option value*. The latter value is associated to the fact that, by engaging in stage $i$, one acquires the option (but not the obligation) to engage in a future activity that might bear further economic value.

This mechanism is very similar to financial options traded on stock exchanges. In financial markets, an investor can buy a *European call option* on a security (the "underlying asset") which gives her the right, but not the obligation, to buy that security at a given date (the "exercise date") and at a given price (the "exercise price"). At the exercise date, should the security's value be greater than the exercise price, the investor will exercise the option and profit from the difference. Conversely, should the share's value be less than the exercise price, the option will be worthless. The price of the option can be calculated as its expected value, which depends on the difference between the current price of the underlying asset and the exercise price, the time before the exercise date comes, and the volatility of the underlying asset's price.

A project in two stages, A and B, bears a strong analogy to a call option, with the former representing the option and the latter the underlying asset ("if you invest in A you will be able, if things go right, to invest in B"). Cost of project A is equivalent to the price of the option, its duration to the exercise date, the cost of project B to the exercise price and the uncertainty in the value of project B to volatility. However, not being associated to a traded security, we will speak of a *real option** (i.e., associated to real activities) instead of a financial one.

The valuation of projects as real options is not an easy problem to solve. Valuation methods used for financial options (e.g., the *Black and Scholes** formula) are generally not applicable, since they require the use of parameters that are not available for non-traded assets. Specific methods have therefore been developed, such as the replicating portfolio (Copeland and Antikarov 2001). Such methods are relatively complicated and require specialist knowledge, which has somewhat limited their diffusion and prevents us from discussing them in depth. For a

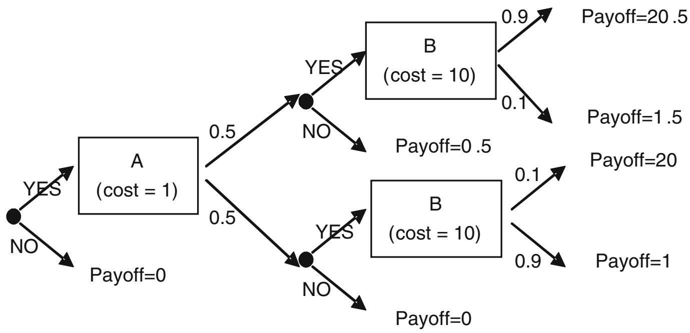


**Fig. 9.9** Using decision trees for a first-approximation valuation of project-based real options

rough-cut valuation, it is possible and intuitive to represent real options as decision trees, with the awareness that the approach might, however, not be very precise.

For example (Fig. 9.9), suppose that a firm must consider investment in a two-stage project with stages A and B, whose costs respectively are 1 and 10. A has a 50 % chance of being successful, and this determines the success probabilities of B and the related outcomes (if A is successful, B's likelihood of success is high, and vice versa).

If one does not consider the option value of stage A, the decision maker must choose among the following alternatives (9.5), (9.6) and (9.7) and will rationally choose doing nothing.

$$\text{NO (don't start any project): payoff} = 0\,M€ \tag{9.5}$$

$$\text{YES}-\text{NO (start project A only): payoff } = (0.5 \times 0.5 + 0 \times 0.5) - 1 = -0.75\,M€ \tag{9.6}$$

$$\text{YES}-\text{YES (start A and B): payoff } = (8.6 \times 0.5 - 7.1 \times 0.5) - 1 = -0.2\,M€ \tag{9.7}$$

Instead, if one considers an alternative with options (start A and go on with B only if A is successful), the payoff will be as in (9.8):

$$\text{payoff} = (8.6 \times 0.5 + 0 \times 0.5) - 1 = 3.3\,M€ \tag{9.8}$$

Phase A therefore has an intrinsic value equal to −0.75 *M*€ (as in 9.6). However, if one also considers it as an option with respect to B, its value climbs to 3.3 *M*€ (as in 9.8). Therefore, its option value with respect to B will be the difference between the two and equal to (3.3 + 0.75) = 4.05 *M*€.

### 9.4.3 Optimization Methods

Financial criteria provide information on the profitability of individual projects, but fail to compare projects against each other and to consider their mutual relationships. To this purpose, one can use optimization methods. Project selection can be modeled as a mixed-integer optimization problem in which the firm attempts to maximize the combined economic value of the selected projects, at the same time complying with constraints in the use of resources. A simple optimization model is the following:

Sets:

$i = 1 \ldots m$ is the set of resource types;
$j = 1 \ldots n$ is the set of candidate projects;
$t = 1 \ldots T$ is the set of planning "time buckets" on which planning is performed, up to a horizon $T$.

Parameters:

$r_{ijt}$ is the use of resources type $i$ by project $j$ at time $t$;
$v_j$ is the NPV of project $j$;
$d_{it}$ is the availability of resource type $i$ at time $t$.

Decision variables
$x_j = 1$ if project $j$ is started, $= 0$ if it is not.

$$\max \sum_j v_j * x_j$$

subject to

$$\sum_j r_{ijt} * x_j \le d_{it} \quad \forall \mathrm{i, t}$$

$$x_j \in \{0, 1\} \quad \forall \mathrm{j}$$

The model is based on the standard *knapsack problem** used in Operations Research. The model can be developed further in order to include interproject constraints. For instance, if projects $j'$ and $j''$ are mutually exclusive, one would add a constraint such as $x_{j'} + x_{j''} \le 1$. Or, if project $j'$ can be started only if project $j''$ is also started, the constraint to be added would be $x_{j'} \le x_{j''}$.

An optimization model such as the one outlined above is characterized by significant computational complexity. In the case of small project portfolios, the model is straightforward to develop, implement and solve with general purpose spreadsheets such as Microsoft Excel® and their optimization functions (i.e., Excel Solver®). For larger portfolios, computational complexity can be too much for simple optimization tools. Therefore, dedicated solver engines ought to be used, which of course leads to a limitation on the applicability of such methods.

When using optimization models, decision makers usually tend to be skeptical of "black box" algorithms that dictate which projects should be started and which should not. Consequently, it is generally best to use optimization models in an iterative way, i.e., "playing with constraints". Decision makers can start from the initial solution and think of deviations they feel might work well, force them by adding or removing constraints and run the algorithm again to see the impact on the objective function, thus performing "what-if" analysis. This allows evaluating the implications of the different alternatives on the project portfolio and on its overall profitability.

### *9.4.4 Multicriteria Methods*

Financial and optimization methods are based on quantitative information, such as financial flows and effort. Given the strategic nature of project portfolio management, decision makers must consider a wide number of dimensions that can have both quantitative and qualitative character. As a pure example, since it would not possible to provide an exhaustive list of such dimensions, one can have:

- Economic and financial aspects (e.g., NPV, PBT, etc.)
- Operational aspects (e.g., effort required, budgeted cost, time required, etc.)
- Difficulties involved (e.g., market and/or technology risk, project complexity, ease of further implementation, etc.)
- Relation with the firm (e.g., coherence with existing or desired corporate competencies, strategic alignment, relevance for competitive positioning, etc.)
- Target (e.g., market, customer segment)
- Attractiveness for the target (e.g., product features, ease of use, etc.).

Some of the qualitative dimensions listed above could be included in the frame of quantitative methods with some ease. For instance, risk can be captured by using discount rates. However, it has already been highlighted that this "translation" can be complex and subject to mistakes. For other dimensions, such as "strategic alignment", the translation would inherently be difficult and quite arbitrary. Therefore, given the impossibility and the potential incorrectness of translating a set of heterogeneous criteria in quantitative and monetary terms, it is conceptually and practically advisable to use specific evaluation methods.

Among the many multicriteria methods available in literature, the *Analytical Hierarchy Process** (AHP) appears to be the most suitable, since it has the aim of structuring objectives around a strategic direction. This is done by structuring a hierarchy of criteria, and identifying the values of relative weights so that they may faithfully mirror a previously defined strategy. From a technical point of view, AHP performs this weighting of criteria and evaluation of alternatives through pairwise comparisons, which are then followed by a validation of the coherence in the

| Weight | *w1* | … | *wn* | | |
|---|---|---|---|---|---|
| Criteria | *c1* | … | *cn* | | |
| Threshold | ** | … | medium | Above? | Score |
| Project1 | *** | … | low | x | x |
| Project2 | *** | … | medium | v | v |
| … | ** | … | high | … | |
| ProjectN | ** | … | medium | v | v |

**Fig. 9.10** An example comparison table for multicriteria evaluation of a project portfolio

overall results. However, despite the appropriateness of AHP to PPM (Lockett et al. 1986; Levine 2006), its diffusion in this context is relatively limited, due to some controversial aspects and risk of making mistakes in its use. Given the length of the discussion that would be needed to cover this topic, readers are referred to specific contributions in literature (Saaty 1980; Roy 1996; Belton and Steward 2002). Instead, we will describe a much simpler and mainstream—though methodologically questionable—approach, based on comparison tables.

The method consists in defining a set of criteria, in assigning weights to each criterion based on a qualitative scale (e.g., 1–5), and then evaluating each project against each criterion, again using a qualitative scale. Additionally, a threshold score might be assigned to criteria, so that projects will be considered only if all thresholds are met. Each project whose scores are above the thresholds, will then be given an overall score that is computed as a weighted sum, as in the example provided in Fig. 9.10.

The firm's strategic intent is expressed *ex-ante* through the choice of criteria, their weights and the related thresholds. The method is very appealing because of its simplicity and also because of its transparency, since the reasons leading to the decision of selecting or excluding a project are evident (as a matter of fact, the method is often used by public agencies when awarding procurement contracts or research grants). However, its quantitative fundamentals are quite weak. Performing weighted sums when both scores and weights are based on cardinal scales is one first and obvious issue. Another potential problem comes from the use of a "flat" set of criteria, a number of which may be highly related to one another, and this may lead to inadvertently overweighting them. Therefore, caution should be taken when using a method of this kind. One can be confident of the outcome if it is used to create a first ranking and then a broad grouping of projects (e.g., "highly attractive", "moderately attractive", "unattractive"). It may be somewhat more critical to use it for discriminating among individual projects, especially if differences between project scores are narrow.

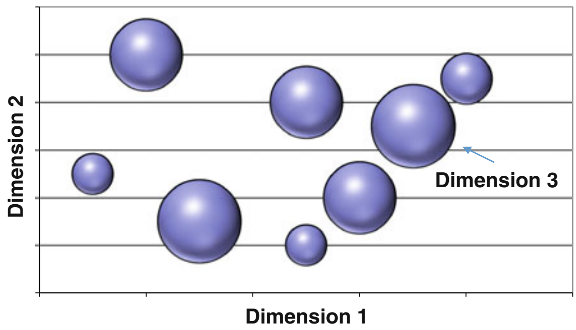


**Fig. 9.11** A bubble chart representing a project portfolio

### 9.4.5 *Mapping Methods*

Another widely used approach for supporting the project selection process is based on graphical representations of the project portfolio. This approach is attractive and widely used, since maps provide an intuitive way to represent and study the "big picture" of a complex project portfolio, and are fairly easy to implement with spreadsheets. The only caveat to be remembered is that a map provides a visual representation of the problem, but not guidance of what to do with it. Even more, a

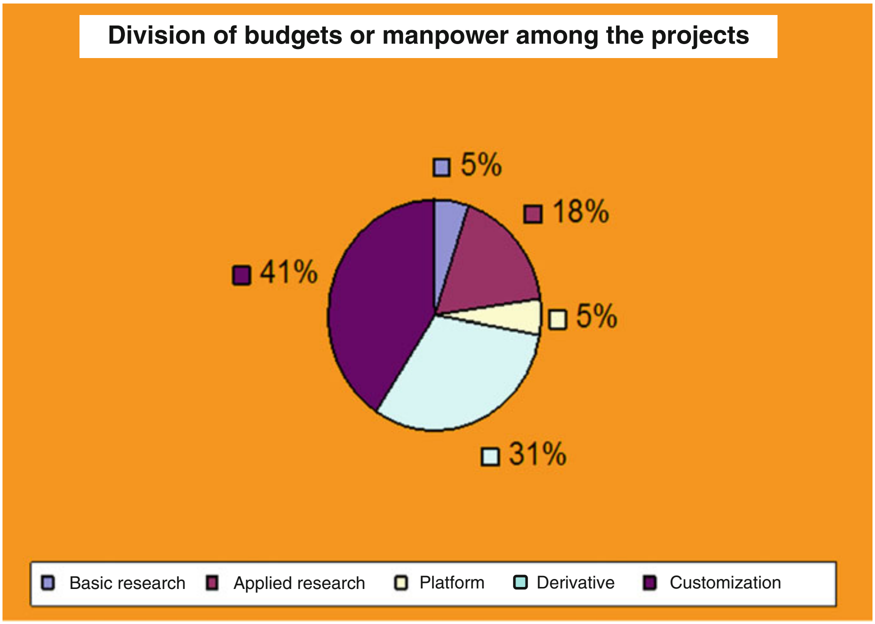


**Fig. 9.12** A pie chart representing a project portfolio

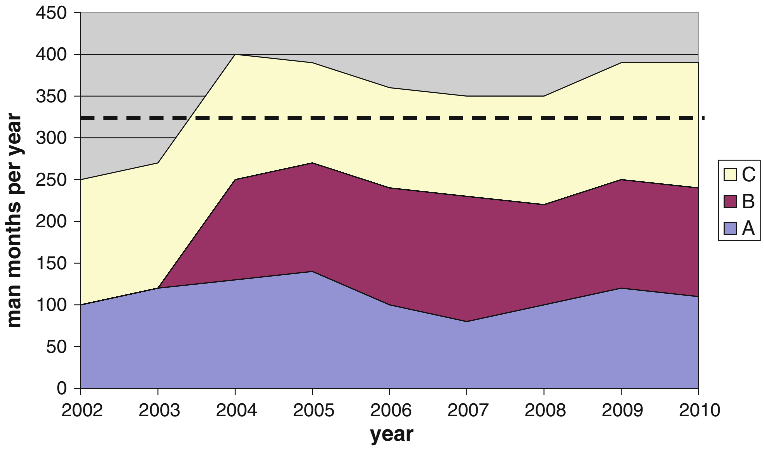


**Fig. 9.13** An area chart representing a project portfolio

visual representation leads to an inherent bias to developing a balanced solution, which may not necessarily be the optimal one.

A project portfolio map is usually based on a selection of quantitative and qualitative dimensions, which can be drawn from the list provided in the previous section. One popular graphical representation is the bubble chart (Fig. 9.11), in which the x and y axis represent two dimensions that the company considers to be relevant to its strategy and decision-making effort. Each project is then located on the xy plane, with a third dimension being the size of the bubble, and representing the "size" of the project.

Alternatively, project portfolio maps can represent the division of budgets or available manpower among the individual projects, or among project categories. This can be done either with pie charts (Fig. 9.12) or, by adding the time dimension, with area charts (Fig. 9.13).

## 9.5 Best Practice in Project Portfolio Management

The previous discussion has shown that project portfolio management is a quite demanding process, which requires significant managerial attention. Empirical research on firms that have engaged in project portfolio management (Cooper et al. 1999) shows that satisfaction with PPM is associated to the quality of the process, and to its alignment to the strategic needs of the firm.

Specifically, one first element of best practice is associated to the degree with which the PPM system is made explicit and clear, and then rigorously applied. A PPM system with unclear rules, and which does not effectively determine the fate of projects will be next to useless, since all actors will quickly learn ways to get around the system and keep their favorite projects in the pipeline.

Moreover, best practice suggests combining "hard" financial elements together with "soft" and qualitative ones. This insight suggests making a combined use of financial and multicriteria ones. For instance, financial methods could be used to perform a preliminary screening of candidate projects. Multicriteria methods could be used to refine the selection by assuming a broader perspective. Then, managers could go back to financial methods in order to suggest changes to the portfolio and/or to individual projects in order to refine the solution further.

Finally, projects should not be considered in isolation, but in aggregate. This is important because projects compete for resources that are scarce and generally hard to reproduce. For this reason, the real cost of project X is not simply the accounting cost involved, but the opportunity cost of the greater value that could be gained if X were not activated, thus allowing freed resources to work on project Y. This suggestion leads to the obvious conclusion that comparisons between projects must be performed. This can be done in a rigorous way with optimization methods, but also in a more intuitive and visual way by using mapping methods.

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# Chapter 10
# Organizing Product Development Activities

With this chapter, we depart from the high-level and strategic perspective that has characterized the discussion up to the previous chapter, and start delving deeper into the operational aspects of managing innovation and product development activities. In doing so, we will consider the organization of applied research and product development projects together, not in the ignorance of the differences existing between these two fields, but because the managerial challenges that characterize them make them nonetheless quite close to one another. This chapter will deal with organizational aspects and focus on human resources, while the following Chap. 11 will view such activities as business processes.

The first main statement that can be made in discussing the organization of innovation activities is that they generally require an *ad hoc* organization, regardless of the overall organization of the firm that hosts them. The reason is that innovation activities are very different from other typical corporate processes, with respect to knowledge intensity, involvement of actors from different corporate functions and duration. In order to provide a broader discussion on similarities and differences between innovation and other corporate activities, one can refer to the following Table 10.1.

As a consequence of these peculiarities, it is quite customary for firms to define an organizational structure dedicated to innovative activities that leans on, but is somewhat different from, the overall organization. In defining these *ad hoc* structures, two opposing criteria of organizational design must be managed. One criterion adopts a process view and focuses on communication flows, stipulating that organizational proximity between actors should depend on the strength of the information flow between them. Therefore, if Mr. A and Mrs. B have to exchange a lot of information, we will tend to locate them into a same unit, regardless of the fact that Mr. A might be a software engineer, and Mrs. B a specialist in logistics. The other criterion adopts a "functional view", and stresses that resources with similar skills and jobs should be located in the same organizational unit, since this will lead to greater specialization and efficiency in the allocation of work. Hence, if we locate software engineers Mr. A and Mr. C in the same unit, the firm will benefit because this unit will be highly focused and potentially more proficient. Moreover, whenever Mrs. B will need to work with a software engineer, management will have the choice of making Mr. A or Mr. B available, depending on their workload.



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_10

**Table 10.1** Similarities and differences between innovation and other corporate activities

| | Similarities with innovation activities | Differences from innovation activities |
|---|---|---|
| Research | Objects being discussed are technically similar, as are the language and methods being used<br>Both activities are highly knowledge-intensive | The purpose is different (i.e., producing abstract versus commercially useful knowledge)<br>Research is based on explicit and formalized protocols and knowledge, and tends to specialization, while innovation tends toward multidisciplinarity<br>Both use abstract languages, such as mathematics, but innovation makes a more extensive use of representations of concrete artifacts (e.g., technical drawings, prototypes, etc.)<br>Most researchers work for non-profit institutions that grant freedom to perform research within a wider scientific community. These communities (or "invisible colleges") set research agendas and use conferences and journals to promote the field, and to appraise the scientific merit research results and individuals. Conversely, innovation is not as free and tends to occur within boundaries of hierarchical and for-profit organizations |
| Administrative and business-support activities | Both are highly information-intensive. Incremental innovation activities are often significantly repetitive | In administrative activities, knowledge is incorporated into codified processes, and actors are supposed to simply follow them<br>Innovation activities are knowledge intensive and more unpredictable than administrative ones, with respect to duration and outcome |
| Production activities | These activities share the focus on obtaining concrete artifacts | Innovation activities have the goal of producing knowledge allowing the production of goods and services. Conversely, production activities can be seen as "users" of such knowledge |

As it will be discussed in the following, organizational design is mostly concerned with striking the right tradeoff between these two criteria, given the type of projects the organization is trying to work on.

Before tackling this discussion, a word of caution ought to be spent on the limitations of organizational design, especially when focusing on communication flows. When one attempts to design an organization that is suitable for dealing with a given type of innovation problems, he is assuming that the kind of problems to solve, the skills and competencies required and the communication flows that are likely to occur are all known. In other words, it is assumed that the problem is well-defined, "problem setting" is completed, and that resources must simply be arranged for effectiveness and efficiency. When dealing with incremental and competence-enhancing innovations, this is likely to be the case. However, if a firm intends to work on architectural or radical and competence destroying innovations, this would be a somewhat lofty assumption. Moreover, a focus on communication invariably leads to concentrating on the explicit information flows that can be traced and documented, but not on the many microlevel communications that naturally occur in teams, and certainly not on the conversations that individuals have with themselves when solving problems. As a conclusion, most of the following discussion will be applicable to incremental innovation occurring in medium-large companies, and for projects with a relatively long duration. Conversely, the discussion will have to be considered with some caution in case of radical innovations, or of very small firms and short projects.

## 10.1 What Do We Know of Organizations Engaged in Innovation Activities?

R&D and innovation activities have been studied since the '70s, when a young researcher at MIT, Tom Allen, decided to concentrate on this topic and published his results in a seminal text that remains a key reference in the field (Allen 1977). Allen's studies stemmed from the intuition that development and innovation activities were different from research, since engineers and designers—despite some common traits—acted in markedly different ways from scientists. It is striking that the validity of Allen's findings has been repeatedly confirmed by researchers up to now. This despite modern organizations can rely on an ICT weaponry that was unimaginable in Allen's times, when information was stored in books and technical documents, and communication could only occur on paper or verbally, with face to face contacts or over telephone lines. At this moment, it is not clear whether the continuing validity of Allen's findings is due to the intrinsic nature of innovation activities, or whether ICT simply has not *yet* been able to make a sufficient impact. Therefore, a large part of this section will be dedicated to presenting and commenting these seminal results, in the consciousness that—at some point in time in the future and in specific industries—its validity may become weaker.

### 10.1.1 The Role of Literature and Formalized Knowledge

People who are involved in research and innovation may be engaged in different activities, but generally share a common educational background in science and technology. They may have attended the same universities, are likely to have used the same textbooks during their undergraduate studies, and to have read and written similarly structured research papers and thesis during their graduate studies. One might therefore expect that, once engaged in their professional lives, they will have a similar attitude toward literature and make similar use of it.

In fact, researchers' entire profession revolves around literature. A researcher will cite previous literature in order to express the current state of the art in her field and to support the relevance of the research challenges she is working on. She will use literature to define research hypothesis, to explain and justify the validity and appropriateness of the methods and protocols used, and the findings will be compared to hypothesis and to other results found in literature. Once published, her findings will enrich the body of literature, thus allowing other researchers to cite the paper, to build on it and, in doing so, granting the researcher recognition in the community and a quick career.

Somewhat surprisingly, when one observes engineers and designers involved in development work, the picture changes significantly. As Allen discovered, literature has a very limited role as a basis for action and as a source of knowledge. When observing a sample of projects, he found that nearly 70 % of solutions to technical problems were sourced from personal contacts, either from peers and colleagues, or from customers. Only around 20 % of the solutions were derived from literature, with the rest undefined. On a more detailed analysis, which consisted in comparing similar projects performed by different organizations,[1] he found that the use of literature as an information source was negatively correlated with the quality of the solution. By delving deeper in this curious finding, he realized that this was not due to the use of literature *per se*, but to the fact that inexperienced personnel would make a greater use of literature, but not get much out of it. Conversely, experienced developers would achieve good results without using literature, but relying on their own knowledge or on interpersonal communications.

Following this finding, one can conclude that using literature in technical work is not harmful, but that it is not enough to make up for lack of experience. The reasons can be traced to the relationship between knowledge and innovation. As it has already been amply discussed, innovation activities mainly rely on knowledge that is tacit, "organizationally embedded" in people and routines, and "contextually situated" in the specific technical and business setting the firm is operating in. Conversely, literature tends to incorporate knowledge that is codifiable, abstract and

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[1]Allen had the chance of studying dual-supply projects, in which a customer awarded similar development contracts to two different suppliers, in order to minimize risk. This was an ideal research setting, since it allowed him to compare the activities being performed by different organizations, using the same project content.

general, and aimed at a much broader audience. Therefore, its applicability in a specific setting will be somewhat limited, and will depend on the availability of some actor able to identify the most appropriate knowledge elements, translate them into terms that are appropriate to the problem under hand, and conjugate them with the existing knowledge base. Consequently, and somewhat paradoxically, literature seems to be of limited use to the inexperienced engineers who would need it most, while it could be useful to the most experienced ones, who, however, generally do quite well without using it.

Not unsurprisingly, Allen also found that, the more a written source is close to the company's specific setting and context, the more likely will it be used. Therefore, trade journals will be used more than academic ones and internal technical reports more than conference papers. Moreover, people will search for written sources of information by following a "pecking order" approach, starting from sources they are most familiar with (i.e., books and/or reports available in their own personal archive), and progressively widening the scope of their search (e.g., borrowing from a colleague) until they find a satisfactory answer. This approach is not due to indolence, but to the fact that a source will be close by and familiar if it has been useful in the past and—exception made for radical innovation—it is quite likely that it will still be for the problem at hand too. Moreover, having used a written source before implies that finding the right information and making good use of it will probably not require much effort.

In Allen's times, the managerial implication of this finding was that firms ought to concentrate on the tacit knowledge element, on interpersonal communication, and on the way individuals communicated and accessed their "local" knowledge stores, rather than on building large libraries. Nowadays, a similar lesson can apply too, warning firms to be careful in designing the ICT infrastructure that is supposed to support innovation activities. While a communication component enabling interaction between different actors is undoubtedly important, the idea of building large repositories of codified knowledge risks being ineffective, since each individual will still face the problem of understanding what can and ought be used and how.

### *10.1.2 The Role of Interpersonal Communication*

One key element of Allen's research was the documentation and analysis of "communication acts" between people involved in innovation activities. When this research was originally performed, personnel engaged in development work were asked to fill in paper forms reporting on "with whom did I speak today". Today, similar research is often performed by tracing electronic communications (e-mails, short messages, phone, or VOIP calls), which of course allows collecting massive amounts of data in a much easier way, and then studying the resulting communication networks.

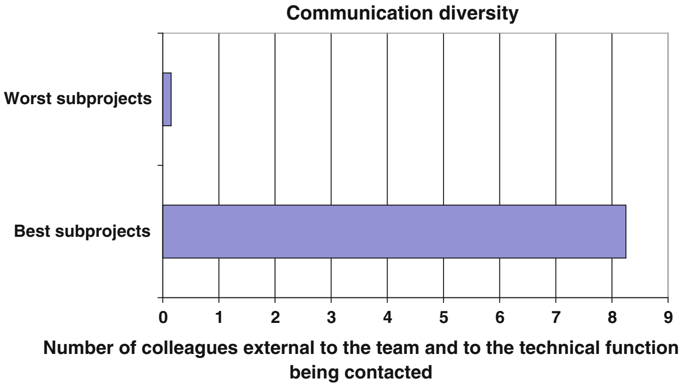


**Fig. 10.1** The impact of external communication on project success

The main idea behind this study was the recognition that interpersonal communication had a key role in suggesting solutions to technical problems. This led to the obvious research question of understanding what kind of communication could ensure the best results. Allen relied on the availability of a sample of "twin projects" in order to provide an answer to this question. Quite surprisingly, he discovered that the intensity of communication within the team (i.e., the number and frequency of communication acts) did not correlate with project success. A similar result emerged when trying to correlate quality of the outcome with the "diversity" of communication within the team (i.e., the number of people to whom the communication acts were directed to). Success therefore did not seem to be an issue of communicating with immediate colleagues. Instead, Allen discovered that the variable that was most correlated to project quality was "communication diversity" with people external to the team and external to the technical function the project belonged to. As it appears from Fig. 10.1, the worst projects were the ones in which no outside contact was made, while the best ones were characterized by a significant attempt to "reach out".

The implication of this finding is that "consultancy networks" are critical to project success and firms therefore ought to nurture them. However, this kind of knowledge sharing activity is not easy to perform. Employees in need of support, and especially the more inexperienced ones, might not know who should be contacted and might feel uneasy in asking for help, since this would imply admitting some degree of ignorance. On the other side, the person who could provide such knowledge might be overloaded with work and be somewhat wary of spending time on someone else's project, especially if this person is inexperienced and therefore unlikely to be able to return the favor. On the opposite, internal consultancy works fairly well among experienced personnel. These are likely to know "who knows what", have a sufficient reputation to not be ashamed of asking for help (especially if in the name of a junior co-worker), and are likely to be heeded to, since they may return the favor in the future.

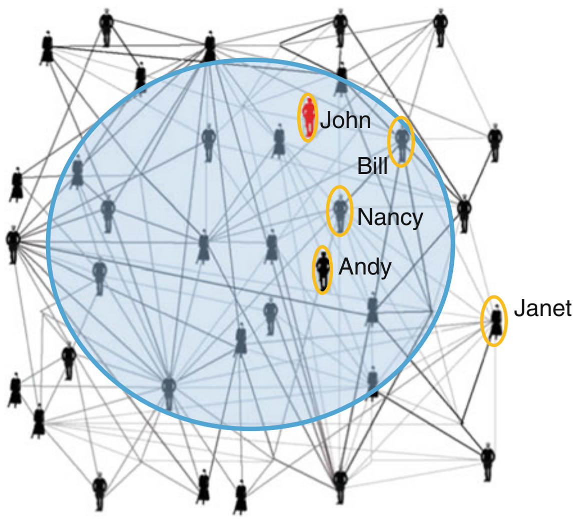


**Fig. 10.2** Gatekeepers' role in technical problem solving

### *10.1.3 The Role of Technological Gatekeepers*

By studying this dynamics, Allen discovered that technical organizations naturally tend to develop *hub and spoke** communication networks, in which a small fraction of actors become hubs, and are responsible for most of "knowledge brokering" both within the firm and beyond. These hubs are given the name of *technological gatekeepers*, and are a key element of technical activities in all industries. As shown in Fig. 10.2, John might have a problem and ask Bill, a "gatekeeper", for help. Bill might not have the answer, but thinks that Nancy, another gatekeeper, might. In turn, Nancy might direct to problem to a young co-worker, Andy, or to Janet, a friend she met at a recent conference and who works for another company in the same area. John will therefore be able to contact Andy or Janet and, should he find it difficult to apply their knowledge to the problem, Nancy and Bill will probably assist him. It is clear that, without these two gatekeepers, John's problem would have never found a solution.

Gatekeepers are a very peculiar organizational actor. With some exceptions that will be discussed in the following, gatekeeping is not a job but, rather, a *role* whose recognition is purely informal. It is therefore quite surprising to discover that technical organizations include a few people (usually around 5–8 %) who are highly critical to the functioning of innovation processes, but that their very existence and their activity occur in an informal way.

Becoming a gatekeeper depends on a particular blend of technical expertise and personal traits that can be found in a minority of individuals. Gatekeepers usually are technically very competent and proficient, which gives them a reputation for professional excellence and, sometimes, the promotion to a supervisory position, such as team leader, which reinforces their visibility. At the same time, they exhibit a high degree of curiosity and eagerness to learn new things and to keep in contact with like-minded people. In short, gatekeepers belong to that minority of technical personnel who routinely read trade journals and are very happy to visit trade fairs, where they spend time discussing technical issues with exhibitors. Moreover, they often spend their own money to become members of professional associations, and then read newsletters, attend conferences and take part to the activities of local chapters. Their role stems from the fact that, by being familiar with the "outside world", and by being at the same time fully immersed in firm's context and its current knowledge base, they are particularly able to tap into the most appropriate source of knowledge or expertise, and facilitate its translation and application to firm-specific problems.

At the same time, the informal nature of the gatekeeping role makes it quite fragile, difficult to manage, and subject to a number of threats. In some cases, a gatekeeper's role might not be recognized at all. Being a highly effective professional, a gatekeeper may be overloaded with work, preventing her from spending some time in knowledge brokering. Missed recognition can also lead to conflicts with both line managers and project managers. In the former case, a gatekeeper might inadvertently challenge their technical authority.[2] In the latter case, internal consultancy might be seen by project managers as a waste of time.[3]

In other cases, a gatekeeper's role may be recognized, but mismanaged. For instance, a firm might recognize a gatekeeper and suggest he spends all of his time in knowledge brokering. However, not having to personally perform technical activities any more, this will gradually lead him to lose that deep contact with the technical context that provided the roots for the gatekeeping role at the beginning. Quite often, in recognition of her competence, a gatekeeper might also be promoted to a managerial position. At this point, the nature of her work changes quite dramatically, since technical contents will give way to administrative ones, and this too will hinder the gatekeeping activity.[4]

In order to avoid these problems, firms have tried to come up with organizational solutions for supporting gatekeepers and providing them with incentives. One of these solutions is the so-called *dual ladder* career path. In such a system, talented

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[2]Think of a junior employee telling his boss "*Mr. Jones, you are telling me that my solution is wrong and will not work. But I asked David, whom we all know is a great gatekeeper, and he told me it's surely going to work, since he knows company X has successfully applied a similar approach*".

[3]Imagine a project manager saying "*Alice, we all know you are a great developer and you come out with great solutions, but you spent all yesterday helping out with those other two projects. Remember you are full time allocated on my project and we are running late for next week's review meeting. Please don't make me say this again*".

[4]Promotions are also well-known to be subject to the so-called *Peter effect**, that states that personnel will tend to be promoted to their "level of incompetence". In other words, people are promoted based on their performance in their current job, which can be a bad predictor of the performance they might have in their next career step. After promotion, in case this latter performance is poor, the person will not be promoted any further, and will therefore be stuck into a job he is not capable of performing well.

technical personnel are assessed for their specific capabilities and directed to either a traditional managerial career, or to a technical one. In this latter case, the person is progressively relieved of operational work, allowed to become a "knowledge manager" in a given domain, and given a widening set of responsibilities on gatekeeping and on coordinating colleagues who are involved in the same career path at a more junior level. In the most structured of these organizational settings (Hirsch 2006), these responsibilities may include:

- the creation and development of *communities of practice** facilitating knowledge sharing among personnel in the same domain, which is especially important in large and dispersed organizations;
- support to the human resources function, for activities such as recruiting, assessment, professional development, and resource retention;
- support to technical functions, by working on the assessment and standardization of technology, support methods, and tools.

Dual-ladder career path systems are very appealing, but their implementation is by no means trivial and can run into many problems. For instance, it is not easy to find the right balance between technical and gatekeeping activities, and between internal knowledge sharing and external networking. Moreover, salary issues can be quite complex to solve, since a credible dual-ladder career path would require having comparable salaries on both "ladders". This can sometimes be hard to justify from an economic perspective and to implement on a contractual basis. Moreover, it can lead to jealousy between people belonging to the two ladders, which end up in professional lives that are very different from one another.

If one attempts to compare initial and recent research findings on gatekeepers, not much has changed, despite the role of ICT and its impact on organizations. In fact, ICT has made it easier and cheaper to codify knowledge and to share and access it. This has led to a huge increase in the amount of available information and knowledge. Now, all this knowledge requires higher-level and tacit knowledge in order to correctly filter and interpret it, understand its implications and limitations, and apply it. In a way, instead of making gatekeepers obsolete, ICT seems to simply have increased the need and broadened the scope of their activity, which now involves helping others find the right information in digital repositories.

Concerning the sources used for technical problem solving, research tells us (Dodgson et al. 2007) that personal communication is still dominant over codified knowledge. At this moment, there is no way to know whether this is an inevitable feature of technical problems, or whether it is due to the fact that ICT systems are still not able to be an effective substitute as far as knowledge management is concerned. However, ICT is having a key impact on innovation activities with the diffusion of simulation and virtual prototyping systems. Thanks to these systems, technical solutions can be searched for extensively and somewhat cheaply through trial and error, instead of relying on prior knowledge. It is therefore possible—though this hypothesis still must be verified—that the role of gatekeepers might be progressively reduced, because simulation and virtual prototyping tools will enable relatively inexperienced people to experiment and innovate even without having an extensive communication network feeding them with hints and insights on potential solutions.

### 10.1.4 The Role of Innovators

Gatekeepers, as described above, are technical problem solvers who therefore are key actors in innovation processes. However, they are not, *stricto* sensu, innovators themselves. If we consider an innovator to be a person capable of matching a market need and opportunity with a technical solution, this latter role appears to be quite wider and more strategic than that of the gatekeeper.

Firms do not only need gatekeepers, but they also need innovators to guide the innovation process with an entrepreneurial mindset (Cohn et al. 2008). Framing and managing the role of the "innovator" within established firms is a relatively recent topic on which literature is still quite scarce. Given their strategic role, innovators must of course be included in the top management team. Due to organizational inertia and path dependency it would be deceptive to think of a separation of roles in which innovators propose ideas, the board decides on which should be followed, and functional managers look after execution. However, it is not clear how these "innovators" could be identified, based on a somewhat elusive talent, follow a specific career path—in which criteria for promotion are definitely different from the mainstream ones—and end up joining the top management team. Some firms have a clear dualistic leadership that brings together innovators and execution-minded talent, but this can usually be traced back to the original founding team (e.g., Bill Hewlett and David Packard). Moreover, quite seldom does this lead to a permanent organizational and leadership structure (the main exception being firms in the field of luxury and fashion, which usually have distinct managerial and artistic directorships).

Given the difficulty of understanding what innovation talent is, research on this topic has mostly been carried out by comparing the approaches to problem-solving taken by widely acclaimed "innovators" with respect to "ordinary" executives. Following Dyer et al. (2009), innovators seem to score much higher on cognitive capabilities such as making associations between seemingly unrelated elements, observing situations and placing deep questions, experimenting, and networking. A similar approach has also been taken by organizational psychologists, who have recently started dealing with the topic, by identifying personal traits that appear to be prominent in innovators, with the objective of facilitating their identification through assessment tests (Potocnik et al. 2014).

Firms willing to explicitly foster innovation talent often adopt intrapreneurship schemes (a concept that was introduced in Chap. 8). For instance, 3 M and Google are known to allow employees to spend 10–20 % of their time on personal projects. A company like Adobe has instead introduced a number of processes to foster

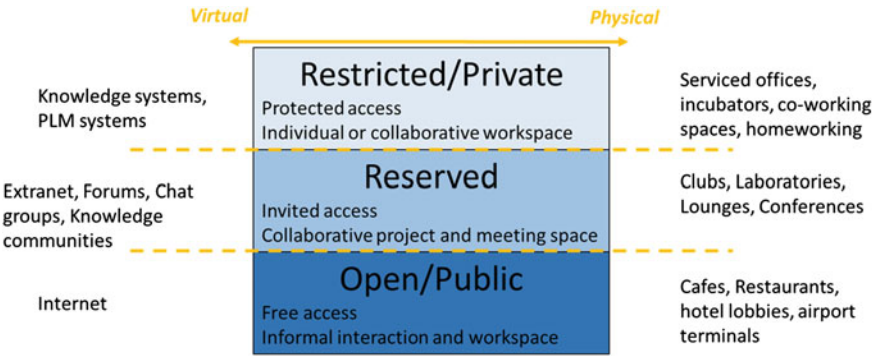


**Fig. 10.3** The contemporary variety of physical and virtual workspaces (modified from Hardy et al. (DEGW) 2008)

grassroots innovation. For instance, employees can "incubate" their ideas in Advanced Technology Labs, under the guidance of "idea mentors" and of "entrepreneurs in residence", following a process that mimics the process with which startup firms are supported by accelerators and funded by venture capital funds.

### *10.1.5 Space and Office Layout*

While studying communication flows between individuals, Allen discovered that office layout had a major impact. Specifically, and quite unsurprisingly, he discovered that the probability of information exchange in a given time interval between any couple of individuals decreased quite dramatically with the distance that separated their respective workplaces. The probability of having one weekly communication act would fall to a meager 10 % when this distance would be greater than 15 m, in the case of people having some kind of organizational linkage. The same probability would occur at a distance greater than 5 m for people not tied by such a linkage. Recent research (Hansen and Løvås 2004) confirmed this finding, showing that knowledge exchange depends on geographic proximity, together with previous acquaintances and relatedness of competencies.

If one couples this finding with the previous one, which stated that project success is associated to speaking to multiple people not belonging to the same project team, a major problem arises. How can a company create the opportunity to have all these "external" communication acts, without having to squeeze everyone in a 5 m radius from one another? The obvious answer is to design office layouts with the aim of creating opportunities for multiple informal acts of communication.

One first solution is to adopt *open space* (or *open plan**) layouts, in which distance between people is reduced and it becomes easier to notice if a colleague is busy, go up and talk to her. While open space layouts do create greater opportunities for communication, they have important drawbacks that anyone who has worked in one can easily confirm, such as noise and lack of privacy. The latter can be quite disturbing, especially in case of firms that are unaccustomed to evaluating employees on results, and where employees may therefore be afraid of being constantly monitored by managers.

Another solution for stimulating informal communication is to create "nodes of attraction" in which employees can go and spend some time. The most obvious node of attraction is the coffee area, which can be designed in such a way that employees will find it comfortable enough to stay for a relatively extended break. In this case, conversation will very easily shift from initial general topics and some office gossip, to the discussion of technical problems and to the exchange of views and knowledge pertinent to the projects participants are engaged in. Other nodes of attraction can be specially designed corridors and atriums, departmental services (such as printers and photocopiers) and so on.

Some firms have adopted more extreme solutions, such as the *non-territorial office*. This kind of layout includes different areas, intended for different types of work (e.g., individual desks, isolated areas for thinking, tables for working in small groups, large conference rooms, etc.). In a non-territorial office, no one has an assigned desk, but people move from one area to the other, depending on the work to be done at that moment.

In general, playing with space allows managers to influence behavior and communication flows in a way that formal directives would probably not be able to achieve. For instance, creating a large "project room" or "war room" will attract employees working on the same project and automatically decrease the strength of their connection with their functions and line managers.

Thanks to cooperation between corporate managers and architects, a number of R&D centers[5] have been designed with an explicit aim of fostering informal communication between employees, allowing them to easily keep abreast with problems and achievements and exchange knowledge.

The concept of workplace is nowadays becoming ever more complex and difficult to manage, since it is no longer limited to the physical office one commutes to every day (see the DEGW report, Hardy et al. 2008). Along with physical workspaces, employees engaged in R&D operate in virtual workspaces where they exchange information, store results of their work and are assigned tasks related to their projects. At the same time, knowledge workers can operate in a wide range of workspaces (Fig. 10.3), which includes private facilities (e.g., company premises, or their own home), restricted areas (e.g., airport lounges and co-working areas) and

[5]For example, most IBM facilities have been designed around the objective of facilitating communication among employees. Other examples are the Renault Technocentre in Guyancourt (focused on interactions between different engineering departments), and the GM development center and plant in Spring Hill (aimed at creating links between engineering and production). Noteworthy is also the LTU Design Observatory in Lulea University (Sweden), where engineering activities and communication are experimentally stimulated by acting on the built environment and a number of innovative technologies that are incorporated in it.

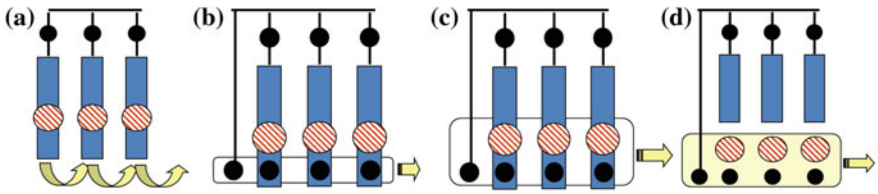


**Fig. 10.4** The four standard organizational forms used in innovation activities. Functional (**a**), lightweight interfunctional (**b**), heavyweight interfunctional (**c**), and autonomous team (**d**)

public spaces (e.g., cafes and hotel lobbies). A detailed discussion on this issue and on its managerial implications would lead us too far away from the focus of this textbook. However, managers involved in innovation activities should nonetheless be aware of the complexity of the way and the places where intellectual work is currently being carried out.

## 10.2 Organizational Design

As discussed at the beginning of the chapter, innovation activities are usually carried out within specific organizational structures. After having introduced the main elements that characterize these activities, it is possible to examine the organizational forms usually adopted by companies and investigate their suitability for innovation projects of different types. Organizational forms are principally defined by the following features:

- the existence, or the non-existence, of a project manager responsible for the project, the scope of his responsibility and the authority granted to him with respect to the resources that work in the same project;
- the degree of separation between resources working in a project and the corporate functions they belong to;
- the degree with which the project requires highly specialized resources;
- the degree with which the project requires close coordination between corporate functions. In this context, coordination implies the identification of balanced solutions to technical design tradeoffs that pertain to different corporate functions. For instance, the choice of a material for a product can impact manufacturing costs, technical performance, and can also have implications on customer service. These tradeoffs will have to be solved both *ex-ante*, when specifying the product, and *ex-post*, when sorting out problems that have been neglected earlier on, therefore managing the resulting design changes.

By blending these four features, four "standard" organizational forms can be defined. Figure 10.4 portrays these forms, with functions being represented by the vertical bars, managers with black dots, while dashed circles represent the resources involved in the project.

- **Purely functional organizations**. In this case (Fig. 10.4a), work is performed within functions by resources that are not permanently assigned to projects. Information is handed "over the wall" from one function to another (e.g., marketing defines a product brief, product engineers then design the product, and manufacturing engineers finally define the process). Coordination is only managed by functional managers, who may not have the time and the knowledge of the specific project to do it effectively. Consequently, this form is suitable only in the case of projects for which interfunctional coordination is not very critical. This form has advantages, such as the efficiency due to resource pooling within functions and the high degree of technical competence that is allowed by specialization—something that is very useful especially if technological progress is rapid. Another advantage is connected to the simplicity of having resources reporting to a single—albeit possibly ineffective—authority.
- **Lightweight project teams**. This organizational form (Fig. 10.4b) can be considered to be a somewhat minor adaptation of the previous one, aimed at solving the coordination problem that was highlighted above. It has the advantage of requiring a traditional, functionally oriented firm, to make minimal change to working habits and organizational culture. Work is still carried out within functions by resources who are not permanently assigned to the project. However, technical coordination is performed by a "lightweight" team composed by a project manager and one representative per each function. Neither the project manager, nor the functional representatives have formal authority over the resources that are working on the project. However, thanks to frequent interaction, they are in the position to influence their work and have the opportunity of creating an effective flow of information that may solve most *ex-ante* and *ex-post* coordination issues. The major drawback of the lightweight team form lies in the ambiguity between the responsibility given to the project manager—which usually consists in delivering the prescribed project results on time and on budget—and her lack of formal authority. This ambiguity is often exacerbated by the fact that—since lightweight teams do not directly manage resources—firms will tend to staff them with junior professionals in order to reduce costs. Now, should significant problems arise, it would be quite hard to imagine a junior project manager taking a tough position with a line manager. This issue can be somewhat abated if the company runs multiple projects under the lightweight team approach. In such case, the firm may appoint a senior program manager to oversee all these projects, have junior project managers reporting to him, and assigning him responsibility for interactions with functional managers.
- **Heavyweight project teams**. This organizational form (Fig. 10.4c) corresponds to a matrix organization, in which functions have the responsibility of developing technically competent resources, who are then formally assigned to one or more projects. Resources still work within functions, must report to line

managers concerning their technical performance, but report to team leaders and project managers for their work in the project. Interfunctional coordination becomes much stronger, given that resources are assigned to projects and strongly involved in its evolution. Moreover, project managers are given formal authority over resources and are in the position to solve whatever problems may arise. This organizational form is therefore quite suitable for projects that involve architectural change. At the same time, this form has some disadvantages too, the main one being the cost deriving from the senior personnel involved in project management, and from the impossibility of using resource pooling, which may lead to idleness of resources. Moreover, the deep involvement of resources in projects can lead to some degree of separation from their technical functions, which in turn reduces their specialization and—potentially—their technical proficiency. A final and major drawback of the heavyweight project team form is related to the complexity of the dual reporting mechanism. In the case of project-based firms (e.g., engineering consultancies, engineer-to-order manufacturers, etc.), this problem is usually quite manageable, since resources are accustomed to work in a matrix organization, and because there is a clear separation in the duties of functions (i.e., to nurture resources) and of projects (i.e., to use these same resources to create economic value within projects). The problem can instead be quite severe in the case of organizations that are not project-based. In this case, functions might see the assignment of resources to project work as a hindrance to their normal operations, which can lead to tensions or to the assignment of "second-best" personnel. For instance, a plant manager might not be very happy to know that his best process engineer must spend half of her time for the next three years in a product development team, instead of making sure that the plant runs smoothly and efficiently.

- **Autonomous teams**. In this case (Fig. 10.4d), the firm pulls resources out of their functions and creates a team that is completely autonomous, geographically co-located, and under the complete supervision of a project manager. This arrangement leads to a very tight coordination between team elements and project phases. The separation from corporate functions allows greater freedom to experiment but—on the other hand—a lower degree of specialization and capability to tap into existing corporate competencies. Furthermore, the autonomous nature of the team leads to lower efficiency, since capacity must be *ex-ante* allocated to the project team, without relying on other personnel belonging to functions. This organizational form is therefore suitable for projects that involve radical and/or competence destroying innovations. Another critical aspect is associated to the duration of the project. Autonomous teams work well either for projects with very short duration (e.g., a task force set up to solve an urgent problem, or to quickly develop a radically new product concept) or for projects that will effectively never end, because the team becomes the nucleus of a new and permanent corporate division. Conversely, it can be quite difficult to disband such a team at the end of a medium–long-term project (e.g., 2–3 years), since resources will have to be reintegrated in their original functions after a long absence, during which career paths in the function may have evolved substantially, while their competencies may have become obsolete.

Following this discussion, companies should to analyze their project portfolio and identify the organizational form that is most suitable per each major project category. The ability of using different organizational forms allows the firm to practice the "ambidexterity" introduced in Chap. 3, with the coexistence of innovative activities that have different nature and are managed appropriately.

At the same time, the firm should try to avoid introducing too many differences in its organizational arrangements, so that its personnel does not have to spend too much time understanding the way they are supposed to operate, and to whom they are supposed to report within each specific project. Therefore, a firm may decide to work with lightweight teams for the majority of projects, and occasionally use autonomous teams in order to introduce a next-generation product.

## 10.3 The Influence of Globalization

When discussing organizational design, an emerging issue is related to the management of geographically dispersed and culturally diverse teams. This dispersion is due to the increasingly global footprint of corporate operations. A firm may have several R&D departments located in different parts of the world. Alternatively, the R&D department in one country may have to jointly design a product with a subsidiary located in another country and with a set of suppliers who operate from other parts of the world.

A central enabler of this globalization of product development activities is the progress of Information and Communication Technology. These tools allow personnel engaged in innovation activities to continuously keep in touch and exchange both structured (e.g., a 3D model of a physical object, a dataset of experimental data) and non-structured information (e.g., a quick exchange of views through a messaging system). People are becoming ever more accustomed to using systems of this kind even when they are physically located close to one another, and this can decrease the difference they perceive when they have to cooperate with colleagues who are located at a high geographic distance.

Literature (Bierly et al. 2009) tells us that effective cooperation is based on trust between colleagues. Cooperation through virtual communications does not generate as much trust as face-to-face meetings do. At the same time, virtual cooperation seems to need a lesser amount of reciprocal trust, though it does not cancel this requirement completely. Therefore, it might be helpful to set the groundwork for a project that must be based on extensive virtual communications by planning some preliminary physical meetings or co-located work. Virtual communication also leads to greater independence in individual work, which requires greater clarity of objectives and a more structured approach to project management.

## 10.4 Project Staffing

A final aspect of organizational design, which is particularly relevant when dealing with geographically distributed teams, is connected to staffing, which consists in identifying team leaders and individual team components to be assigned to the project. The choice of team members is of course critical to project success. A team made of up of competent professionals who are able to cooperate effectively, exploiting their mutual complementarities, is far more likely to achieve the desired results than a team in which individual competencies are lower and/or members are not able to work well together. Staffing must therefore simultaneously look at individual profiles and at the degree of diversity within the team. In general, researchers agree (Adler 2002) that the relationship between team diversity and performance follows an inverted U-shaped curve. Some degree of diversity provides richness to the internal debate and to the team's capability of generating new ideas, but up to a given point, beyond which the difficulty in communicating and understanding each other starts prevailing.

When assigning personnel to a team, there are a number of dimensions over which these ought to be evaluated. The main such dimension is the match between the requirements coming from the project's activities and the candidates' "hard skills", or professional competencies. This first dimension is generally quite easy to appraise, since data on the knowledge and competencies possessed by technical personnel is usually well known and is often codified in "competencies repertoires". However, other dimensions may be highly relevant as well, and might be more subtle to manage, since companies are not likely to keep profiles of personnel under these perspectives. Among such dimensions one can mention:

- **Personal traits**. Examples include degree of openness, optimism, capability to work in teams, and should be considered with some allowance for diversity. A team made of pessimistic members is not likely to explore anything but the most conservative of technical solutions, just like a team made up of optimists might suggest solutions without sufficiently exploring their potential risks.
- **Gender**. The topic is not sufficiently researched, but anectodal evidence from industry suggests that men and women engaged in innovative activity tackle technical problems from different perspectives and following slightly different cognitive approaches. This being the case, diversity in team composition is likely to enrich the innovation process and lead to better results.
- **Experience**. Aside from the obvious statement that experience is valuable, research tells us (Gunther and Ehrlenspiel 1999) that novice and experienced designers tackle technical problems following quite distinct approaches. The former are usually more methodical and use a predefined process as their main problem-solving strategy, possibly in order to make up for their relative lack of experience. The process followed is therefore well-structured and well documented, starts with an in-depth clarification of the problem, and is followed by the proposal and analysis of potential solutions. Conversely, experienced designers tend to rely on intuition and experience, and follow a process that is

generally poorly structured and documented, but quicker. Problem clarification, generation of solutions and their evaluation occur simultaneously and iteratively, with a constant focus on the artifact being developed and its subsystems, and not on a predefined process and its phases. Under this perspective, team staffing implies making choices over which kind of problem solving strategy should be preferred, and on finding ways to manage the conflicts that may arise when personnel who follow completely cognitive approaches have to cooperate.

- **National culture**. Since the '70s, researchers have realized that national culture has an influence on the way with which people operate in organizations and tackle the problems set in front of them by their profession. One of the first and best known contributions on this topic is Hofstede's (1983) research on cultural dimensions, performed while he was working at IBM on a huge sample of more than 100,000 individuals. Hofstede identified five "cultural dimensions" which define national cultures, and namely power distance (i.e., the degree with which individuals accept inequality in power or wealth), individualism, uncertainty avoidance, masculinity (i.e., the degree with which values such as power, career, money are preferred over caring for others, quality of life, etc.), and long-termism. Following Hofstede, national culture influences behavior and, therefore, the approach individuals will follow in tackling problems. Moreover, individuals' national culture will lead to diversity within international teams, with the ensuing implications with respect to richness and coordination issues to be faced. Hofstede's findings have often been criticized, especially because differences in national culture explain only a small part of the variance exhibited by individuals. Therefore, the theory can at best be used to provide preliminary guidance, but certainly not as a tool for predicting individuals' behavior. Moreover, with the recent spread of globalization, many knowledge workers have had the opportunity of studying and working abroad, which is likely to reduce the influence of their home country's national culture. However, this latter point has not been researched enough to support more than a reasonable hypothesis.

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# Chapter 11
# The Product Development Process

This chapter can be viewed as a complement to the previous one, since it focuses on the activities that make up product development, rather than on the organization of the actors that carry them out. This perspective fits well to the contemporary approach to management, which is strongly focused on processes. It is also closely related to Nelson and Winter's theory of the firm, that is prevalent in the study of innovation economics (explored in chap. 2), as well as to the "resource based" approach that is popular in the context of corporate strategy (which we discussed in chap. 6).

However, the process-oriented view of product development calls for a comment and a word of warning that are somewhat similar to the one that has also been raised in the previous chapter. When one assumes that there is a predefined process for product development, and that its constituent activities can be *ex-ante* spelt out and arranged, this implies that the problem to be solved is relatively well structured. In the case of ill-defined problems, one cannot *ex-ante* define a solution process, since the process will be "discovered" while solving the problem. Therefore, the process-oriented view will be applicable for product development projects with moderate innovative content, so that prior experience can be used as a guide, and of a sufficient size, which makes the formal and detailed definition of a process meaningful. Conversely, it may not be so applicable in case of small and informally managed projects, and/or very innovative problems for which no clear solution strategy has been identified and formalized yet.

Furthermore, the very hypothesis that a predefined process can exist clashes against the behavior observed in knowledge-intensive professions by Schon (1983, 1995). Schon studied a variety of professionals from technical and non-technical fields. He discovered that they seldom follow predefined strategies, but continuously analyze new information arising from the problem and from their attempts to tackle it, and adapt their problem-solving approach as a consequence. In a way, professionals are involved in a continuous "conversation" with the problem, and follow a cognitive approach that can be termed *reflection in action*. These two visions can, however, coexist, if one considers "reflection in action" to be typical of individuals' behavior, and the process perspective to represent a product development project in its entirety at organizational level.



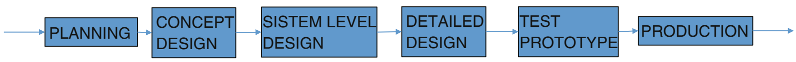
M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_11

## 11.1 The Main Phases in Product Development Processes

Following the resource-based theory of the firm, it is commonly observed that firms are different, and that these differences can be traced to the sets of resources and routines that characterize them. This is particularly true for the product development process. This process will be significantly different from firm to firm and will depend on the industry, on the products being developed, on the upstream and downstream relationships with other firms and, of course, on firms' past history. This said, it is nonetheless customary to define some typical phases that make up the product development process, in the knowledge that these are only for general reference (Fig. 11.1).[1] The following description covers the case of physical products, but can be easily adapted to the case of services too. The presentation shows a sequence of phases and the associated involvement of organizational functions. This is done for conceptual clarity and follows the traditional approach to product development. As it will be shown in the following sections, contemporary practice suggests abandoning this sequential structure and performing these phases in parallel, with some degree of overlap, and/or iteratively.

- **Product planning** is the initial phase of the product development process. In this phase, the firm has the objective of defining the new product from the joint perspective of market (i.e., "to which customers is it addressed? What needs does it have to tackle?") and technology (i.e., "what functions and performance should characterize it?"). Product planning is a highly interfunctional and interdisciplinary phase, in which representatives from most corporate functions, from marketing to customer service, are to be involved. Product planning generally starts with the dual exploration of tacit or explicit market needs and of technological opportunities. The prevalence of either of the two determinants depends on the type of innovation (i.e., incremental or radical) the company wishes to pursue. Based on this research, the firm will reach a very high-level definition of the product that is often termed *product brief* or *design brief**. The product brief allows the *positioning* of the product with respect to target market segments and to the firm's and to competitors' existing product portfolios and *product pipelines**. Then, the firm will develop a detailed description of *user needs* and *user requirements*. In parallel to these activities, product cost will be evaluated and a *business case* for the product will be defined, analyzing the returns from expected sales and comparing them against the required

[1]Firms will be likely to specify their own specific product development process at some level of detail. Typically, this is a mandatory requirement for firms who wish to certify their quality systems around international norms, such as ISO 9001. A well-defined product development process can also help when engaging in product development jointly with customers and suppliers. Moreover, the process model can be used as a template for managing product development projects, and as a basis for defining workflow on information systems.




| | | | | | | |
|---|---|---|---|---|---|---|
| Marketing | X | X | | | | |
| Purchasing | X | X | X | | | X |
| Finance | X | | | | | |
| Technical office | X | X | X | X | X | |
| Manufacturing | | X | X | X | X | X |

**Fig. 11.1** A reference product development process

investment. This business case will be revised at each of the following steps of the process and will therefore evolve from a preliminary feasibility study to a fully-blown operational plan.

- **Conceptual design** is the first activity in the development process that copes with technology in detail. At the heart of this phase is the choice of the technical solutions that will be able to fulfill the previously defined user requirements. As it will be discussed in Chap. 15, these technical solutions will collectively define a *product concept*. The firm must therefore decide whether to use an existing product concept or whether to look for a new concept and a more radical innovation. In this case, they will generate alternative technical solutions leading to new product concepts and make a selection of the one that best matches user requirements and the business case. Given the product concept, the firm will draft detailed *technical specifications* that will provide designers involved in the subsequent steps with a clear idea of the functions and performance levels that the product will have to achieve.
- **System-level design** is the stage at which the firm makes important technical choices. At first, it will move from the product concept to the definition of a *product architecture* (which—for the time being—can be defined as the list of subsystems that make up the product and their reciprocal interfaces) and make a number of choices concerning the main subsystems and components. Among such choices, *carryover* means deciding on which subsystems or components are to be taken from previous products, and which are to be introduced anew. Percentage of carryover, computed by component count or by component value, is often used as a proxy for the innovative content of the product. *Custom* versus *off the shelf* decisions are associated to the choice of which subsystems are to be developed specifically for the new product and which are to be selected among an existing offering coming from either the same firm, or from outside vendors. Finally, *make, develop or buy* decisions dictate the distribution of work between the firm and its suppliers in development and production. "Make" implies both activities are performed in-house; "develop" refers to internal development and external production; "buy" means that both activities are assigned to suppliers. System-level design is also concerned with defining interfaces between subsystems at functional and geometrical level, and with the specification of

subsystems and components. This latter task broadly depends on the nature of the specifications, which can be either *localized* or *general*, respectively, depending on whether they are related to a single or to multiple components.[2] In the case of general specifications, it is necessary to *apportion* specifications to each component. The task is not trivial, since it will generally lead to finding the right balance in a complicated system of tradeoffs.[3] This phase is also concerned with the preliminary definition of all the systems that will interact with the product throughout its lifecycle (e.g., production, maintenance, logistics, etc.).

- The **detailed design** phase is where most of the engineering work is carried out. Materials and components are chosen and designed in detail, while calculations are carried out to dimension them so that the required specifications are met. Decisions carried out at the system-design phase will eventually be reviewed.
- The **prototyping and testing** phase can be separated from detailed design for conceptual and historical reasons, though contemporary firms tend to perform them in parallel through simulation. The conceptual distinction is due to the fact that detailed design is concerned with generating or detailing solutions, while prototyping deals with verifying and validating them. Testing can be performed analytically, through simulation or on physical prototypes. The role of simulation on virtual prototypes is progressively growing, due to its predictive power and low cost. When used, physical prototypes are usually developed in steps and range from preliminary (or *alpha*) prototypes, in which components and manufacturing processes can be significantly different to the final ones, intermediate (or *beta*), in which components and processes are similar to the final ones, and *pilots*, which are built using final components and production processes. Testing on prototypes is often carried out for regulatory purposes too. Many products must in fact comply with governmental regulations, and require the awarding of a certification by the competent authorities before they are commercialized. In most cases, certification requires tests to be carried out on prototypes or early versions of the product itself.
- **Process design** is involved with the detailed design of processes that will enable the product to be produced, distributed, and serviced. This also involves designing a large number of the resources required by such processes, such as tools, dies and fixtures for manufacturing, service manuals and tooling for field engineers, and so on.

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[2]For instance, in a notebook computer, mass storage capacity is a localized specification, since this specification at product level (i.e., the gigabytes of mass storage the firm wants the computer to have) can immediately be translated into the same amount at the level of the single subsystem that is responsible for it (i.e., the hard-disk or solid-state drive). Conversely, cost, mass, and battery time are general specifications, since they will be associated to a number of different components. Cost and mass will be given by the simple sum of the same specification for all components, while battery time will be a function of battery capacity and energy usage by other components.

[3]In the notebook computer example, should one provide more battery capacity, which will come at a greater cost and mass, or adopt chipsets that use less energy but are more expensive?

- **Product launch and production** is the final phase in product development. At product *launch*, the firm starts to deploy the resources dedicated to production in order to build and deliver products to the market. In some cases, production starts on a limited scale by using *pilot* lines, which will later be backed up by other production resources. During *production ramp-up*, production lines are usually started at a slower pace than the nominal one, so to iron out problems and make sure that its production personnel becomes progressively acquainted with the new product. Firms usually allocate a given time after launch, during which the product and the process will be fine-tuned in order to ensure adherence to specifications and market acceptance, after which the development process is officially terminated. In some industries, such as aerospace, the development process is not ended at all, and remains active until the product is in use. This allows customers to be continually supported with updates and with the possibility of adapting the product according to emerging needs.

## 11.2 Some Peculiar Features of the Product Development Process

When looking at product development as a business process, three distinct features emerge, and namely the "lever effect" exerted by its first phases, the presence of iterations, and the complexity of the work being carried out by designers. These features make the product development process quite different from other business processes and justify specific approaches for its management.

The first phenomenon can be understood by observing the evolution of project costs. At first, one can plot the cumulative costs *incurred* by a firm during the process. This leads to an *s*-curve (continuous line in Fig. 11.2), since the first phases usually are relatively inexpensive, while the majority of costs are incurred in the detailed design, prototyping, and production design phases.

At the same time, one can plot a curve of cumulated committed costs (dashed line in Fig. 11.2) that shows the share of overall costs being *determined* by each phase. This curve shows that the most important market and technological choices are taken during the product planning and system-level design phases.[4] So, the later

[4]For instance, at the beginning of the development process for a consumer electronics product, the team may decide to adopt a completely new material for the casing of the device. The cost incurred for taking this decision can be very low (i.e., some research on materials properties, a few calls to suppliers and a few minutes of debate during a meeting). However, once taken, this decision may determine a substantial portion of the subsequent costs since the casing built with this new material will require a given amount of engineering work during detailed design, followed by the search for new suppliers, investments in tools and dies, and so on.

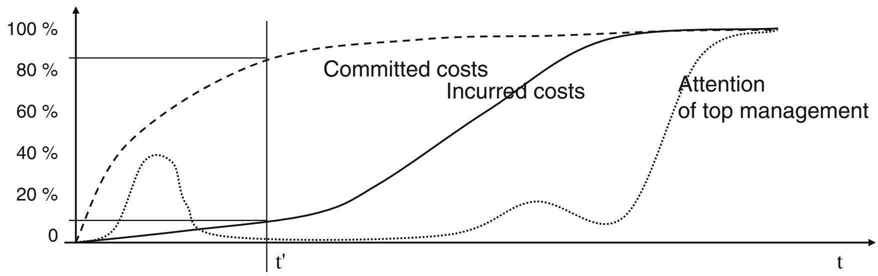


**Fig. 11.2** The “lever effect” in the early phases of the product development process

phases will entail a significant expenditure, but will be unable to make a significant difference in the overall costs, if not by making sure that activities are properly executed and major mistakes are avoided.

In summary, while the early phases of the development process have the very important task of “doing the right things”, the later phases of the development process are simply concerned with “doing things right”. Moreover, while reversing a decision early in the process can be relatively inexpensive, changes occurring during the later phases may have a very strong impact on development cost.

The gap between incurred and determined costs that characterizes the initial phases of the development process leads to a “lever effect”, and explains why managerial attention ought to be very high at the onset of the process. In fact, many development processes fail because top management starts paying attention only toward the end, when tangible results show up but—unfortunately—when it is either too late or too costly to overturn earlier choices (dotted line in Fig. 11.2).

A second distinctive feature of the product development process is the presence of iterations. Most corporate processes are conceived to be performed only once, and any iteration is usually considered as a fault to be avoided. This is not true for the product development process. As in any problem solving process, and especially due to its creative nature, it is absolutely normal to revise choices when designing a new product. Iterations can occur at individual level, when a designer makes a choice, challenges and tests it, and goes back to revising it in order to improve the solution. Iterations can also occur at team level. For instance, a designer may choose a component and may then be forced to revise this decision, because a colleague in charge of designing another component highlights an incompatibility. Similarly, an iteration might occur because a colleague representing another corporate function may point out that a given design choice would make the product difficult to manufacture or service. Finally, iterations can occur between development projects, when choices made for one product may impact another one. The role of iterations in product development is so significant, that the major approaches to its management differ in the way they manage iterations.

The third feature of the development process is related to the way with which individual designers operate with respect to the broader objective of developing a complex product (Mihm 2010). Designers operate under significant information asymmetry, since managers usually do not have a full understanding of the specific technical choices they make, and this leads to a principal-agent problem. At the same time, designers tend to focus on the specific tasks and components that are assigned to them, and are relatively unaware of the overall design problem. This naturally leads them to develop "beauty ideals" that are locally optimal, but that can collectively lead quite far away from the global optimum. Moreover, designers are usually subject to incentives and managerial pressure with respect to timeliness and technical quality of the solutions they come up with. Therefore, in order to make sure that problems will not arise later on, they tend to "over-engineer" their decisions.

## 11.3 From Sequence to Concurrency

Over the last century or so, firms have developed a number of management techniques for coping with product development and its peculiar features.

A first approach, typical of the greater part of the XX century, came from *Taylorism**, that was the dominant paradigm in the management of production activities. The product development process was finely split into separate tasks and assigned to specialist engineers. Each design task was performed independently from one another, and its completion would lead to an "over the wall" transfer of information to downstream tasks. In theory, the process did not consider any kind of iterative interaction between design tasks. In practice, iterations would be informally managed by a *chief engineer*, who would engage in a constant dialog with the designers and solve any tradeoffs that might arise among the technical solutions they would come up with.

Around the 1970s, artifacts became much more complex with respect to the number of components and the heterogeneity of technologies, which made the Tayloristic approach and the behind-the-scenes management of iterations ineffective. Product development therefore became subject to *design reviews**. The project was divided in major phases, at the end of which *milestones* were defined. At each milestone, a design review would be carried out in order to go over the design choices made in the previous phase, and attempt to identify any inconsistency or mistake that might create problems later on. Design reviews would be carried out by managers, customers, and peers. The latter could be taken in either as experts in the same technical areas that were involved by the previous development phase, or as representatives from the areas that would be in charge of the downstream phases.

In the 1990s, researchers studying product development in the automotive industry realized that Japanese carmakers were able to perform product development in much shorter timeframes that Western ones, and with a significant reduction in engineering changes after product launch. By studying their managerial approaches, they discovered that this was due to a strong parallelization of design activities that was termed *concurrent engineering** (Clark and Fujimoto 1991). In the mainstream interpretation of concurrent engineering (Fig. 11.3), design phases are not performed sequentially,

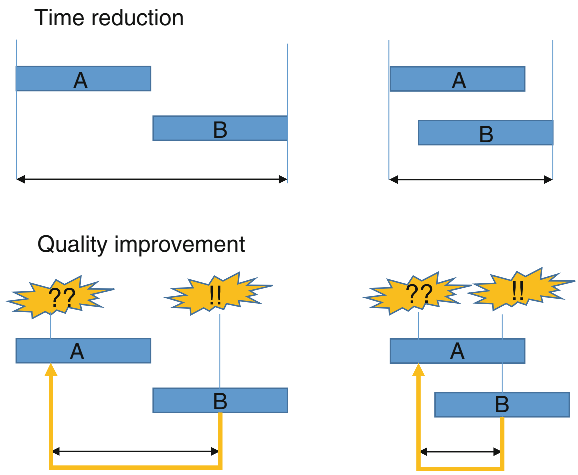


**Fig. 11.3** Concurrent engineering and its two advantages

with a single large transfer of information on completion of the upstream phase to the downstream one. Instead, activities are performed in parallel, with a continuous and often informal exchange of information.

This parallelization can lead to two main advantages. The first advantage is the decrease in the time required to complete the development process. Although each phase may require more time to be completed, the overlap leads to a shorter overall lead time. The second advantage is related to design quality. In the traditional, sequential, approach, mistakes are spotted much later during the process, after substantial time has lapsed and much design work has been carried out. When the mistake is found, it is generally difficult and costly to go back to the original design choice, change it, and unwind all subsequent decisions. The overlap makes it possible to find mistakes much earlier, and their correction substantially easier.

Alongside to these advantages, concurrent engineering has been reported to exhibit some drawbacks too. Downstream engineers are forced to operate on imprecise and vague information, and must often revise their work when upstream information changes. If the firm does not provide proper incentives, they will be tempted to not perform their activities until the upstream phases are ended and the design is officially *frozen*. This behavior might lead them to provide some words of advice to upstream designers, but not to effectively perform work on the tasks that are assigned to them.

Moreover, managing parallel tasks with a frequent exchange of information is not easy from a project management perspective, in which activities are usually linked by simple end-start constraints. As shown in Fig. 11.4a, one solution might consist in planning a given number of information transfers and fragment activities correspondingly, but this leads to a substantial increase in the number of activities to be managed. Alternatively (Fig. 11.4b), a firm may opt for an informal approach, view the parallelized activities as a single one, and leave its management to the

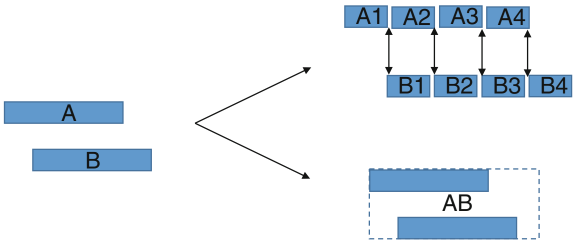


**Fig. 11.4** Concurrent engineering viewed from a project management perspective

inner dynamics of an interfunctional team.[5] This approach works well when the size of the activity and of the associated team is reasonably small, but cannot be applied for larger projects. Specialized techniques for coping with this issue will be introduced in Chap. 12.

Researchers have identified some additional and somewhat less evident pitfalls of Concurrent Engineering (Crawford 1992). The first one is related to the underlying belief that reducing time to market should be a key priority. This may lead development teams to focus on limited technical objectives and incremental innovation. Moreover, when facing difficult technical problems, time-pressed development teams will be likely to "cut corners", without even considering the opportunity of making substantial revisions to design choices. The reliance of concurrent engineering on interfunctional teams also makes project success heavily dependent on factors that are quite difficult to control and manage, such as the internal climate, the skills of the project manager, and so on. At the same time, teamwork requires to spend considerable time exchanging information with colleagues both individually and in meetings. This places a limit on the time available for personal work and, aside from reduced productivity, reinforces the incentive to narrow the technical scope of the project.

## 11.4 Tradeoffs in the Product Development Process

When managing a product development process, a number of tradeoffs have to be dealt with. In order to correctly understand this issue, it is possible to analyze the entire product lifecycle from an operational and financial perspective, as shown in Fig. 11.5.

[5]These teams are often named with the set of responsibilities that is assigned to them. For instance, a *Design and Build Team* will be tasked with making sure that a subsystem is designed to specifications and its manufacturability is ensured.

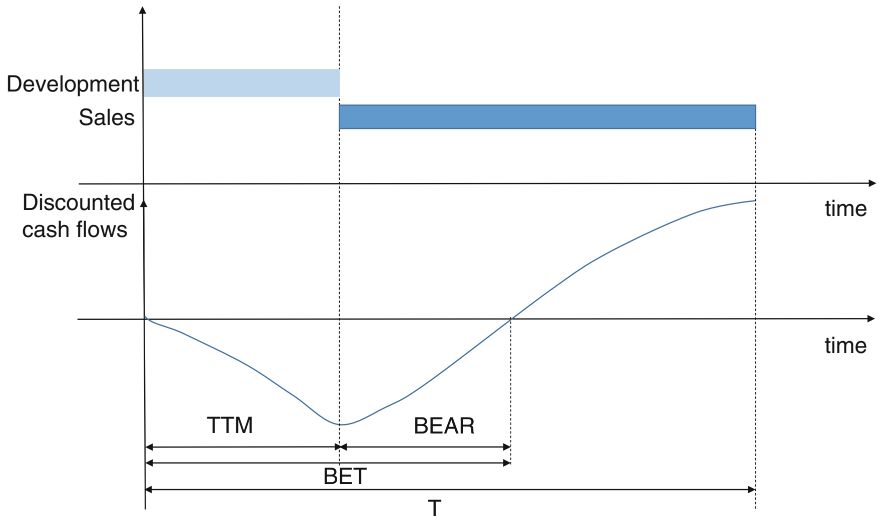


**Fig. 11.5** The operational and financial structure of a product development process

A firm must first of all define a planning horizon *T*, beyond which it expects the product to become obsolete, or it does not feel able to make forecasts. Evaluations will therefore be made up to time *T*, which can be called *window of opportunity*. The planning horizon can be split in two phases, the former dedicated to product development, up to *start of production* (SoP) and then product launch, and the latter to sales.

From a financial viewpoint, the development phase leads to negative cash flow, while the sales phase determines positive cash flows that will eventually allow the firm to recoup the investment made. The slope with which the cumulated cash flow curve recovers after the launch event depends on sales volume (i.e., units sold per time unit) and on the contribution margin (i.e., the difference between unit price and variable cost). Time to market (TTM) is usually defined as the lapse of time between the start of the project and product launch. Breakeven time (BET) is defined as the interval that goes from the start of the project to the time at which the investment is recovered. Breakeven after release (BEAR) is the interval between product launch and the time at which the investment is recovered, and therefore is the difference between BET and TTM.

The product development process is characterized by the tradeoffs between four key variables, as shown in Fig. 11.6.

The first variable is development time, or TTM. Reducing TTM is a key concern for firms, and can enable a number of alternative strategies (Fig. 11.7). The most obvious one is to start the project early and to enjoy a longer sales phase (firm B). Alternatively, a firm (C) may postpone the start of the project, and keep the same duration of the sales phase. By doing this, the firm will be able to develop a more

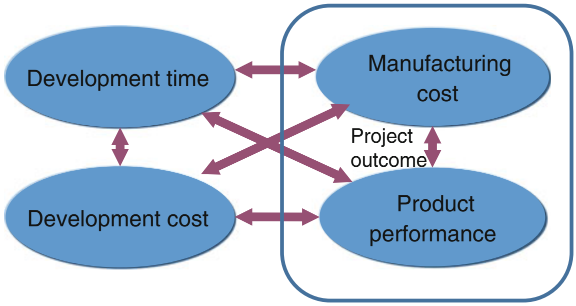


**Fig. 11.6** The main tradeoffs in the product development process

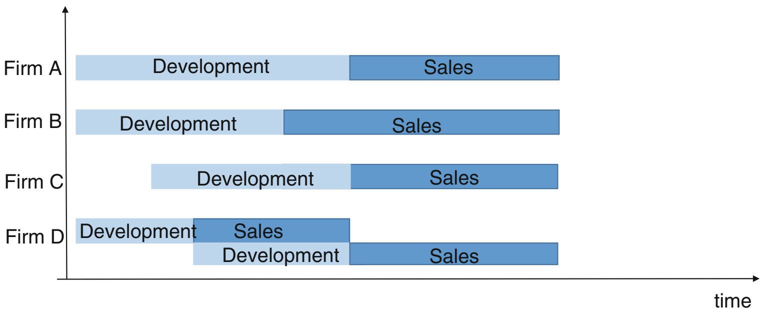


**Fig. 11.7** Strategic uses of short time to market

advanced product, by incorporating up-to-date technology or market needs. Finally, a firm (D) may reduce TTM so much that it can launch multiple products within the same sales cycle.

TTM reduction can be implemented either with managerial techniques, such as concurrent engineering, or by increasing capacity (e.g., using overtime, hiring personnel, or using external consultants), thus investing a higher amount of resources.

The second variable is development cost. A firm may assign a greater or lesser budget to the development process, which the aim of influencing the development time and/or the outcome of the project, i.e., the features of the product being developed.

The last two variables are related to the relevant features of the product, which are product performance and product cost. Achieving higher product performance may allow the firm to position the product at a higher price point, therefore increasing margins, or to keep the same price and gain more market share. Similarly, lower product cost may be used to either increase margins or to reduce the price and therefore increase volume.

In order to manage these tradeoffs, a firm must be able to foresee their financial implications.[6] These decisions can easily be taken if the firm develops and constantly updates a financial model of the product over its lifecycle, and uses it to perform simulations and what-if analysis. A model of this kind is usually a key part of the business case that is drafted in order to obtain approval of the project before it starts, but must be updated and used throughout the project. When working on financial worksheets representing business cases, there are many uncertainties, and the outcomes rest on highly debatable assumptions that might be both endogenous to the firm (e.g., what market share will the product reach?) and exogenous to it (e.g., what will the US Dollar–Japanese Yen exchange rate be in the next five years?). It is therefore advisable not to perform single-point simulations on expected values only, but to envisage a number of scenarios in order to achieve a better understanding of the variance of the outcome and its dependency on key assumptions. Instead of discrete *scenario analysis**, the firm may also decide to use *Monte Carlo analysis** to achieve a broader picture of potential outcomes and their variance.

Analytical studies on the economics of product lifecycles have also been proposed in literature, but are of limited practical applicability, because they rest on very stylized models. It is, however, noteworthy to mention the model developed by Cohen et al. (1996), who recognized a number of interesting features of optimal decisions in product development, which may be considered as general and relatively practical guidelines. The main outcomes of this model are the following:

- A firm should focus its effort on the phases in which it is able to generate higher added value. Conversely, it should consider outsourcing other phases.
- If the window of opportunity $T$ is shortened (i.e., in the case of products with fast obsolescence), the firm should intuitively reduce TTM. However, the optimal reduction should be less than proportional (to be precise, it should be proportional to $\sqrt{T}$).
- In the case of large markets and/or high unit margins, a firm should develop high-quality products even if this requires a greater TTM. The resulting higher quality of the product will lead to greater market share, and the related contribution margins will more than repay the added effort and the initial lost sales. Conversely, in the case of small markets and/or low unit margins, the optimal strategy is to go for incremental innovation (i.e., to pursue smaller advances with shorter TTM and limited investments).

[6]For instance, a firm must be able to estimate the impact of "*delaying product launch by 2 months in order to incorporate a new component that might allow a 2.30 dollar reduction in unit cost*", or "*allowing a 100,000 € increase to the development budget in order to hire a consulting firm that might help develop a better product, with an expected sales increase of 5–10 %*".

- Firms should not use BET as a performance indicator, since this casts an incentive for excessively short and unambitious projects. BEAR is a more balanced indicator, which brings firms closer to the optimal TTM.[7]
- If a firm increases its development productivity (i.e., the increase in product quality per each unit of effort spent), it should carefully consider how to use this advantage. It is usually better to keep the same TTM and substantially improve the product, rather than reducing TTM and targeting the same product quality.

In some cases, firms can dispense with the problem of defining the "ideal" TTM and leave it to the seasonality that is inherent to the market, or is purposely chosen in order to provide "rhythm" to development activities (Brown and Eisenhardt 1998; Souza et al. 2004). When following such a *time-paced* strategy, the firm anchors the launch date for its products at a given period and then decides on the technical contents and the development budget. Launch dates can be determined by demand (e.g., toys must be launched in time for the Christmas selling season), by major trade fairs (e.g., consumer electronics being shown at the Las Vegas CES in January) or by internal traditions (e.g., "the traditional June salesforce meeting in the Alps"). Time pacing makes project scheduling and management significantly easier, since all actors involved learn by experience what should be accomplished at a given time (e.g., "each year our customer X delivers his prototypes in mid-January, and wants durability tests to be completed by the end of February").

## 11.5 The Role of Information Technology

Even though concurrent engineering is mainly an organizational technique, its success depends on the support provided by modern Information and Communication Technology tools. There are two main ways with which ICT enables product development, the first one being product representation and the second one management and transfer of information.

Concerning the former, product development has become ever more *virtualized*, in the sense that products and services may be represented in detail with computer

[7]A number of firms, among which HP (House and Prince 1991), have adopted performance indicators similar to BEAR. This is by no means an easy policy to enforce, since BEAR measures the performance of a project not by looking at its execution, but at its future consequences. This runs contrary to the usual training received by project managers, i.e. to deliver given results on time and on budget, since BEAR takes the completely different stance of looking at how quickly the project will recoup the investment made, *whatever* time and budget has been used. From a project manager's perspective it may seem puzzling that development performance may be calculated by looking at the sales phase. After all, one might argue that what happens during the sales phase depends on functions and managers in charge of sales, production, field service, etc. In reality, this is the very reason why BEAR is a powerful indicator, since it forces managers in charge of development projects to internalize the elaboration of all the processes and assets that will be needed later on and ensure they will work correctly.

models. Three-dimensional representations of physical products do not only allow the visualization of an idea, as in the old technical drawings drafted on drawing boards or on 2D *Computer-Aided Design** (CAD) tools, but also the simulation of the product under multiple perspectives, which collectively fall under the acronym of CA-X. So, for instance, Computer-Aided Engineering (CAE*) tools allow the simulation of cinematic and dynamic behavior of a product, of stresses when subject to forces and of thermal and fluid flows. Similarly, Computer-Aided Manufacturing (CAM*) software allows the modeling and simulation of manufacturing and assembly processes, as well as the disassembly processes needed to service the product and disassemble it at the end of its life. Finally, Computer-Aided Production Engineering (CAPE*) tools enable product developers to represent the production system at a higher level of abstraction (e.g., manufacturing or assembly cell). Analogous simulation tools have also been developed for industries other than manufacturing, such as services (e.g., for simulating business processes), software engineering, and so on.

The availability of multiple simulation tools provides a tremendous support to concurrent engineering, since it allows designers to receive quick and inexpensive feedback on their design choices, without having to engage in costly and time-consuming experimentation on physical prototypes. Virtual prototyping has effectively changed the way with which products are conceived, both at the level of the organizational process and the individual cognitive one (Gupta 1996).[8] In the traditional paradigm, designers had to make the best possible choices and then moved to costly experimentation on physical prototypes to validate such choices, in the hope that everything would go well. In the modern paradigm, designers can develop products by trial and error, using virtual experimentation for exploring solutions. This somewhat reduces the need for *ex-ante* knowledge (though this knowledge does retain value for reducing the time and cost required to converge to a solution). Virtual experimentation also allows product developers to explore innovative solutions that would not have been considered within a traditional product development process, given the time and cost required by experimentation. Simulation also allows *front loading* of the development process, which means spotting problems and critical issues early in the process. At the same time, and since simulation tools provide sophisticated experimentation capabilities to designers, this calls for a broadening of their skills.

Digitalization has also brought up the issue of managing the huge mass of information that is generated and consumed by the product development process. Even in the case of products with moderate complexity, design teams generate a plethora of files for representing the product and its components, which must be multiplied by the number of versions generated at the various project iterations and by the number of different simulations that may be performed on them.

[8]This phenomenon is common to many activities that have "gone digital". Whether it is writing text with word processing software, or shooting photographs with digital cameras, users exhibit the tendency to work by trial and error and to engage in multiple iterations that would not have been possible with traditional means, such as fountain pens and film-based cameras.

Additionally, project documentation may include both structured data (e.g., a database of experimentation results, the Work Breakdown Structure representing project activities, etc.) and unstructured data (e.g., messages exchanged within the development team). In order to manage this information properly, to provide an appropriate operational support, and also to provide some means for capturing the tacit knowledge that is used and generated within the development process, information systems have evolved quite significantly. Early *engineering data management** (or EDM) systems were little more than file managers for CAD-generated data. These were followed by *product data management** (or PDM) systems, which managed all information pertaining to the product during the design phase. The current state of the art is represented by Product *lifecycle management* (or PLM) systems*, which manage all information related to the product throughout its lifecycle. For a deeper insight on PLM systems, readers can refer to Grieves (2006), Stark (2005), Saaksvuori and Immonen (2002) for a general discussion and to Schuh et al. (2006) and Garetti et al. (2005) for reviews of commercially available systems. PLM systems are application frameworks that allow the integration of various modules relevant to product development, based on a common infrastructure. Among these modules, the most significant are:

- **Bill of Materials managers**, able to represent the hierarchical relationships between components under different perspectives (i.e., engineering, purchasing, manufacturing) and to associate files and documents to relevant elements in the BOMs. These different perspectives stem from the fact that each corporate function may have a different hierarchical view of the same product. For instance, designers may prefer functional analysis as a decomposition criterion; purchasing agents may require a decomposition that is based on suppliers or supplier categories; manufacturing engineers may instead look at the assembly sequence with which the product is physically built. The role of a BOM manager is to allow these different views, at the same time ensuring consistency among them.
- **Configuration managers**, able to represent variations of the same product, depending on the features that are applied when serving individual customers or market segments. These modules are charged with ensuring that configuration rules are enforced (e.g., "vehicle X cannot have air conditioning unit Y if engine Z is being used") and must also keep track of engineering changes at product and component level (e.g., "Dishwasher X sold in market Z used pump Y1 from date D1 to D2. From date D2 onwards, pump Y2 must be used") in order to ensure consistency of production and aftersales service.
- **Engineering change managers**, which track the evolution of changes to the product by following design iterations before product launch. Additionally, they manage modifications that are applied after the end of the development project, in reply to faults that are discovered and have to be corrected, or to the normal evolution of components.

- **Component and supplier managers**, acting as a centralized repository of components being used within the firms' collection of BOMs, and that facilitate the standardization and reuse of components.
- **Workflow managers**, able to automate the evolution of the project so that—when an activity is completed—the following steps are automatically initiated, and the people responsible for their execution are alerted and provided with the right information.
- **Vaulting systems**, which represent the main logical repository of information being stored and modified in the development process. In a vaulting system, files are represented by their inner data and by a set of relevant metadata. Whenever an actor accesses a file in order to modify it, the file is *checked out* and other users are prevented from doing the same, in order to ensure consistency. When the actor ends his work, the file is *checked in,* the vaulting system assigns it a new version number, updates the metadata (e.g., who modified it, when and why) and then passes the information to the workflow manager so that other actors who might have to react to this change may be notified.
- **Project and Project Portfolio managers**, which enable the strategic and operational supervision of development activity.

Modern corporations widely use both PLM and *Enterprise Resource Planning** (ERP) systems. While the former support the product development process, the latter support administrative and production processes. Given the different nature of these processes, it is natural for these two types of systems to follow different philosophies. ERP systems support repetitive, explicit, and finely detailed processes, and are therefore focused on automating transactions. Conversely, PLM systems support processes that are knowledge-intensive, somewhat tacit and relatively unpredictable. They are focused on managing information and tend to support—rather than automate—activities. In the context of PLM systems, the degree with which a firm decides to define processes and activities in a normative way leads to a significant tradeoff between efficiency, predictability and repeatability on the one side, and lack of intellectual freedom and willingness to propose new solutions on the other side. Because of this tradeoff, user involvement in the introduction of PLM systems is probably more critical than for any other kind of business information systems (Neirotti et al. 2012).

## 11.6 Flexibility and Agility in Product Development

Most management strategies for product development processes are aimed at coping with the three distinguishing features that were described early in this chapter. Most of all, the "lever effect" that characterizes the early phases of the process has led to developing strategies aimed at ensuring that wrong decisions were not taken, if not early on. Following this perspective, firms have focused on stage and gate systems, feasibility studies and extensive market research. This line of thought appears to be particularly appropriate to a context in which the marginal cost of a design change is very high or, in other words, in which design flexibility is low (Thomke 1997).

When facing particularly turbulent environments, in which markets and/or technology are rapidly changing and very difficult to predict, it is necessary to adopt a completely different approach to product development. If it is not possible to make sure that wrong decisions are not taken, the alternative approach is to make sure that, whatever happens, reaction is possible and inexpensive. By taking this stance, the key managerial question becomes "*given the tools we have, what is the last responsible moment for taking this decision?*" and to use this delay to capture as much information as possible from the environment.

In the case of manufactured products, this might require to use uncommon processes for making components, such as *flexible manufacturing systems**, soft tooling, or *rapid manufacturing techniques**, instead of the traditional processes used in mass production. While unit costs may be higher, this flexibility grants the firm the freedom to make design changes without incurring significant expenses. Thanks to flexibility, firms might avoid traditional market research, launch a wide range of products and continuously adapt their catalog based on the actual market response being observed. This approach, termed *real-time market research* (Sanchez and Sudharsan 1993) is commonly used in services and by Internet companies.

When market and technological uncertainty becomes extremely large, it may become impossible to develop a reliable and complete set of product specifications on which to base the development effort. In this case, it is possible to use the concept of *Lean Development** (Ward 2009). Lean development is based on the idea that that a firm can progressively fine tune its offering, by defining, developing and launching a *minimum value product* (MVP) as soon as possible. The MVP can be tested and continuously revised, improved and fine-tuned according to its performance with respect to marketing and financial metrics, in a continuous and deep interaction with different customers segments.[9] Should this continuous experiment approach failure, the firm should not necessarily abandon the project, but simply make a *pivot*. This means making substantial changes to the product and/or the business model in the attempt to gain the desired results. This iterative product and customer development process should be carried out in the most objective way possible, which implies the need to define a sound and accepted set of metrics.

Another approach that can be used to ensure flexibility is to understand the different dynamics of each activity in the development process, and manage them accordingly. First of all, some product elements may be relatively stable and can be decoupled from the ones that are characterized by a higher degree of turbulence. For instance, a watch manufacturer may follow a slow-moving approach to product

[9] Some authors (Blank and Dorf 2012) talk about "customer development" running in parallel to "product development".

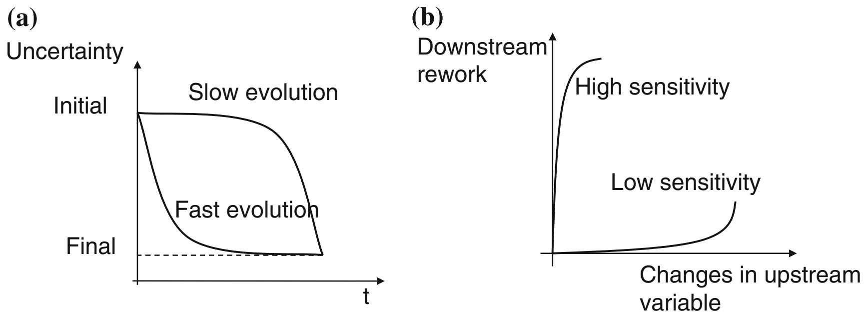


**Fig. 11.8** Managing concurrent engineering according to upstream evolution speed and downstream sensitivity

development for the movements, but create a continuously varying stream of external designs for cases, dials, and straps of its products.

Moreover, when following Concurrent Engineering principles, the amount of task overlap can be defined in an activity-specific way. Following Krishnan et al. (1997), the degree with which two phases should be overlapped or kept sequential depends on the evolution speed of the upstream activity, and on the sensitivity of the downstream one. As shown in Fig. 11.8, an activity has high evolution speed if designers are able to reduce most of design uncertainty quite early, by making major choices at the beginning of the process, and then spending the rest of their time fine-tuning the solution and performing incremental changes. Conversely, evolution speed will be slow if uncertainty remains high throughout the duration of the task, and convergence to the final solution occurs only at the end. It is intuitive to imagine that activities having to do with incremental innovation, proven technologies and well-known markets will have high evolution speed, and vice versa. Sensitivity of a downstream activity to upstream changes may be defined as the relationship between the change in an upstream variable and the corresponding amount of downstream design rework that is required to adapt to this change. Low sensitivity means that limited rework is needed even in the face of significant change, whereas high sensitivity will be present if a lot of rework will be induced even by minor changes. If one relates these two properties, it is apparent that a complete overlap will be possible in the case of fast upstream evolution and low downstream sensitivity, while activities should not be overlapped at all if upstream evolution is slow and downstream sensitivity is high. Intermediate degrees of overlap will then be possible in the remaining cases.

The software industry exhibits a very high degree of turbulence, be it in the case of Internet firms that must continuously adapt their services, or when a software firm must develop corporate information systems for complex organizations in which specifications are not easy to define. In face of these challenges, software engineering has progressively evolved from traditional and relatively bureaucratic approaches to the concept of *agile software development**. Many principles of this approach are easily adaptable to completely different technological domains and industries, and this has led to the *agile product development* approach. Among the techniques used by this philosophy, one can list the following:

- **Rolling-wave planning**, in which scheduling is not computed on the basis of a detailed breakdown of all foreseen activities, from the start of the project to its completion. Instead, a detailed schedule is developed for the immediate future (e.g., 4 weeks) only, and a rough plan is drafted for the remainder. The schedule is updated at regular intervals (e.g., every 2 weeks).
- **Loose-tight planning**, in which activities are classified on the basis of their uncertainty and creative content. Tight planning is performed for activities whose duration is relatively certain, while looser planning allowing for delays is made for the other ones.
- **Time-boxing**. The usual practice in project management consists in structuring projects based on an *ex-ante* detailed definition of activities, and on the ensuing identification of key milestones, each of which is defined around a set of expected results. During project execution, project managers must ensure these results are achieved, and tend to manage the timing at which this happens with some flexibility, occasionally accepting delays. Time-boxing follows the opposite approach, by breaking down the project into regular intervals, often termed *sprints* (e.g., every 2 weeks) and then identifying the expected results at the end of each. No delay is allowed during execution, and project teams are required to report whatever results have been achieved. This method grants a smoother and more regular management style, while the flexibility with which results can be reported becomes an antidote to the common tendency of "over-engineering" technical solutions.
- **Evolving specifications**. Agile development usually shuns away from adopting a clear separation between the product specification phase and the ensuing project execution. Instead, specifications are allowed to evolve over time, with a high number of iterations occurring at the release of new solutions, each of which allows the team to gain a deeper understanding of the problem and to fine-tune the specifications.
- From an organizational perspective, agile development is based on a relatively **informal management style** based on strongly empowered and self-organizing teams. Meetings are carried out informally (e.g., morning stand-up meetings for defining the agenda of the day) and project progress is monitored by defining backlog (e.g., the number of components still to be designed, the number of open issues to be solved, etc.) and providing visual aids to make it evident.

## 11.7 Set-Based Concurrent Engineering

Concurrent engineering has been previously introduced as the parallelization of activities that would intuitively be considered to be upstream or downstream of one another, such as the design of the product and the definition of the related manufacturing processes. Concurrency can also be introduced under another perspective, in which the experimentation of alternative solutions is carried out in parallel instead of iteratively. This approach is termed *set-based concurrent engineering* (Sobek II et al. 1999).

When facing a problem that might be solved by choosing one among a discrete number of technical solutions, companies would generally opt to follow a sequential experimentation, starting from the most promising alternative and moving to the following one in case of failure (Fig. 11.9, left-hand panel). By following this approach, the firm minimizes expected cost, but the expected time required to reach a solution will be high and subject to a high variance. In order to shield the rest of the project from this variance, project managers will assume a high duration of these sequential experiments, and project lead time will therefore become longer. Should the team be lucky and find that the first alternative provides a satisfactory solution, it will generally be impossible to re-plan the project and anticipate its completion. Moreover, the firm will always remain with doubts with respect to the quality of the adopted solution, since nothing will be known of the alternatives that have not been experimented. This can be highly damaging toward the end of the development process, if the chosen alternative might turn out not to be satisfactory enough. In this case, everyone will start asking "what would have happened if we had chosen Y instead of X?", though revising this early decision could prove very costly, if not impossible at all.

A firm following the principle of set-based concurrent engineering will instead experiment with all alternatives (or a subset of them) in parallel (Fig. 11.9, right hand side), and choose the most promising at the end. This way, the firm will certainly incur in higher costs, but with no variance. Moreover, it will benefit from a reduced lead time with no variance at all. Finally, having tried all viable alternatives in parallel, the confidence in the one that will be adopted will be much higher.

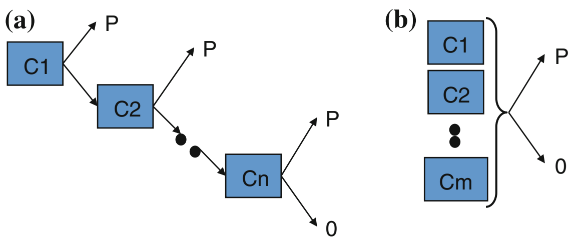


**Fig. 11.9** Set based concurrent engineering

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# Chapter 12
# Project Management for Product Development

After having discussed the process with which product development is performed, it is immediate to start thinking about ways for managing each individual development project. A firm will likely have defined a standard process that provides a general template. However, each initiative will be characterized by some degree of uniqueness, which suggests the use of tools and methods from the field of *project management**. This chapter cannot attempt to cover such a broad field as project management, which is a discipline with distinct and well-known sources and textbooks. Readers are advised to refer to these, in order to gain at least the basic competence that will enable them to apply methods and tools proficiently in the domain of product development. Therefore, a basic understanding of project management is here assumed (specifically, the hierarchical definition of activities in a Work Breakdown Structure, and the generation of a project schedule, based on network techniques such as CPM).

This chapter therefore has the objective of highlighting some peculiar features of product development projects and of the way with which project management can be applied to them. It is in fact intuitive that product development projects are characterized by a degree of uncertainty that is not usually found in other domains, such as construction or event planning, and therefore require a specific approach.

## 12.1 The Nature of Activities and Resources in Product Development Projects

As it has been outlined in the previous chapter and elsewhere in the text, the product development process is characterized by the central role of information. Especially in contemporary practice, the role of virtual (instead of physical) product models has grown to the extent that product development activities can mostly be considered to be information-producing and information-consuming tasks. It comes as a consequence that the translation of the product development process in project management terms is quite straightforward. The development process will likely be represented by a workflow, with activities symbolized by boxes, and information



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_12

flow by arrows connecting the same boxes. *Project activities* will therefore correspond to the same activities outlined in the process. *Project events* will correspond to the ending of an activity and—therefore—to the production of a package of information. Finally, precedence relationships between project activities will be associated to information flows. In short, if activity A provides information X to activity B, there will be a precedence relationship that binds B not to start before A is ended and X is produced (Fig. 12.1).

The transfer of information from activity A to activity B is a critical interface when managing the product development project. In principle, when activity B takes ownership of X and starts, it sanctions the termination of activity A and it provides an implicit acceptance of the validity of information X and of the upstream activities that led to it. We know that, in product development, this is never completely true, and that further iterations are quite likely to occur. Nonetheless, the transfer of ownership of X from A to B implies that both parties do not see any evident problem in this information package, and that activity B accepts to take it as an input. This suggests that some degree of formality ought to be introduced at this stage, which can consist in the signing of a document, the minutes of a joint review meeting, and so on.

When planning the project, the effort, duration, and cost required by activities must also be estimated. In the field of product development this is not always an easy task, since many of these activities can be highly specialized, and only the managers in charge of each are sufficiently knowledgeable to provide such information. This can make a top-down budget allocation process difficult. Conversely, having to accept a bottom-up approach, companies bear the risk that managers may behave opportunistically and ask for more time, effort and budget than they really need. Leaving opportunistic behavior aside, effort, duration and cost of product development activities can seldom be defined with precision, since the creative nature of the process implies a high degree of uncertainty. In principle, it would be advisable to provide probabilistic estimates of such parameters and then run a non-deterministic scheduling of the project, eventually with the use of Monte-Carlo simulation (Kroese et al. 2011; Kwak and Ingall 2007; Drexl 1991). A number of project management software tools can support this approach, but not many companies have sufficient skills in following through with this method.[1] Therefore, it is common practice to make "safe" estimates, in the knowledge that the buffer capacity that is consequently built in the project will at some future time be used by some disruption that has not been properly identified at the time of initial planning.

Finally, when dealing with effort, duration, and cost of activities, firms should be wary of assuming simplistic relationships between them. In principle, it is possible to start from the assumption that effort (usually measured in units such as person-days or person-months) is given by the product of *Full-Time-Equivalent**

[1]Literature on Project Management generally cites probabilistic methods such as PERT. However, this technique has nowadays become quite seldom used by companies in practice.

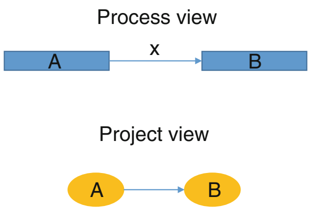



**Fig. 12.1** Translating the product development process in a project management structure

resources being used on average throughout the activity times the duration of the activity itself, or

$$\text{Effort} = \text{FTE} * \text{Duration} \tag{12.1}$$

However, the inverse relationships

$$\text{FTE} = \frac{\text{Effort}}{\text{Duration}} \tag{12.2}$$

$$\text{Duration} = \frac{\text{Effort}}{\text{FTE}} \tag{12.3}$$

(12.2) and (12.3) are not necessarily true, since the resources employed will likely exhibit decreasing marginal productivity.[2] This phenomenon occurs true in any economic activity, but can be considered to be especially relevant if particular skills are required, as in the case of product development. Similarly, it might not be correct to state that the cost of an activity is given by the product of effort and unit cost, since the latter might depend on the actual resources being employed (e.g., two employees may have different salaries, or the firm may decide to use external consultants at an extra cost).

In some instances, uncertainty may also lead a firm to formulate the project plan without determining a single triplet of values for duration, effort and cost, per each component activity. Instead, it may estimate two such triplets, one for the normal execution of the activity and another one for an accelerated (or *crashed*) execution, with $T_{\text{normal}} > T_{\text{crashed}}$ and $C_{\text{normal}} < C_{\text{crashed}}$.

In general, resources engaged in projects can be grouped into three main categories. The first is made up by employees that are allocated to the project "according to use". In this case, their cost is associated to the actual time they spend on the project and—if they are not required to work on the project in a given

[2]For instance, if John is able to complete a job in 6 days, this does not imply that John and Anne will be able to complete it in 3 days. This is because John, who was the first choice, is likely to be more productive than Anne. Furthermore, when both people work on the same task, further work may be required to coordinate them. This may be accomplished by having the two actors dedicate some time to this task, or even require the contribution of a third party, i.e. a manager.

interval—the project does not have to bear the related cost. This reasoning is based on the assumption that the firm has other ongoing projects that are able to saturate the time of resources that are temporarily not being used. If one refers to the organizational forms discussed in Chap. 10, this is common in the case of "functional" and "lightweight project team" arrangements. The second category includes employees that are *ex-ante* assigned to the project for a given proportion of their available time and for a fixed time frame. In this case, which is typical of heavyweight team organizational forms, their cost is charged to the project based on their a priori assignment, and independently of the actual day-to-day usage. Finally, a third category considers external resources, such as consultants. These add flexibility to the pool of internal resources and are generally supposed to be charged on an ad hoc basis, like the employees belonging to the first category, but at higher hourly rates.

## 12.2 The Management of Iterations

A typical feature of product development processes, which has been amply discussed in the previous chapter, is the presence of iterations. In product development it is quite possible for the completion of one activity to lead to a new execution of a preceding activity that had already been terminated. These iterations can be "tight", if the two activities are located close to one another in the project plan, or "wide", if the two activities belong to phases that are distant from one another.

When planning the development process, potential iterations can be foreseen with some ease by thinking in terms of information flows. Referring to the example in Fig. 12.2, activities A, B, and C are *sequential*, since information supplied by A is needed to start B, and information produced by B enables C; activities D and E are *parallel*, since they both use information supplied by C; activities G and H are said to be *coupled*, since both need to use information supplied by the other, and this leads to a clear possibility of iterations occurring between the two. If one looks carefully, coupling is present among the three activities G, H, and I, with a possibly complicated pattern of iterations between the three.

If one tries to translate these information flows into precedence constraints, standard project management techniques cannot be used, since coupled activities

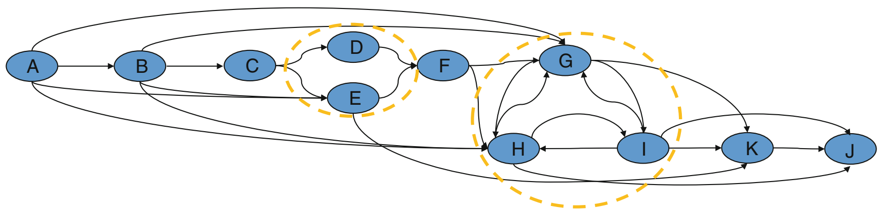



**Fig. 12.2** Sequential, parallel, and coupled activities

lead to “circuits” in the activity network. These circuits make it impossible to define the starting time of an activity depending on the ending time of the precedent activities, since the latter might depend on the termination of the former. Therefore, if ordinary project management methods are to be used in the field of product development, it is necessary to learn how to identify and manage circuits.

### *12.2.1 Identifying Circuits and Iterations*

The identification of circuits can be performed through direct visual examination of the activity network, as long as the project is fairly small. When the project is large, formal techniques should instead be used. One possible approach is to represent the activity network in the form of a Boolean adjacency matrix, which is called Design Structure Matrix (or DSM, Browning 2001; Eppinger and Browning 2012). In a DSM (Fig. 12.3), activities are listed in rows and columns, and an arc (i.e., an information flow) between activity A and B is represented by a non-zero value in the cell at the intersection of column A and row B. In a DSM one can identify sequential activities by observing strings of “1”s that are parallel to the main diagonal and located beneath it. Parallel activities will instead lead to vertical strings of “1”s, located under the main diagonal. Finally, coupled activities can be identified by observing non-zero cells above the main diagonal. The position of non-zero values depends on the naming and ordering of activities in the DSM. Therefore, the identification of coupled activities and circuits as non-zero values above the main diagonal can be performed only after having attempted to exchange rows and columns in order to eliminate them. So, referring to Fig. 12.3, it is clear that activities E, F and G, H and I are coupled, since any exchange of the corresponding rows and columns would move a non-zero value below the diagonal, but bring a new one above. Conversely, activities J, K are not coupled, since a simple

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A | | | | | | | | | | |
| B | x | B | | | | | | | | | |
| C | x | x | C | | | | | | | | |
| D | | | x | D | | | | | | | |
| E | x | x | x | | E | | | | | | |
| F | | | x | x | x | F | | | | | |
| G | x | x | x | | | x | G | x | x | | |
| H | x | x | | | | x | x | H | x | | |
| I | | | | | | | x | x | I | | |
| J | | | | | x | | x | | x | J | x |
| K | | | | | | | | x | x | | K |

**Fig. 12.3** The DSM representation of the project in Fig. 12.1

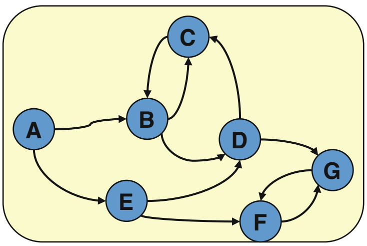
reversal of rows and columns would bring the corresponding non-zero value below the diagonal.

When using DSMs, circuits can be identified by observing above-diagonal non-zero values, after *partitioning algorithms* (Gebala and Eppinger 1991) have attempted to minimize their number. When these non-zero values are close to the main diagonal, the activities are closely coupled and relatively easy to manage, as it will be discussed in the following. When they are located far away from the main diagonal, this implies the possible occurrence of a large-scale iteration that could evidently be quite disruptive for the project. In this case, project managers ought to anticipate and prevent the iteration from happening, for instance by ensuring an early involvement of representatives from the "downstream" activity during the execution of the "upstream" one.

DSMs are very powerful tools for the management of product development processes. Their use is not limited to representing activities and their mutual relationships, but can be extended to other two coordinated matrices. As shown by Eppinger and Browning (2012), it is possible to compile an adjacency matrix for the resources involved in product development, with each matrix value denoting information flow between resources. In this case, the rearrangement of rows and columns allows managers to group resources and form teams based on expected information exchanges. Similarly, and as it will be shown in Chap. 16, a DSM can represent the components or subsystems of the product. Matrix values will represent the existence of intercomponent interactions, and the rearrangement of row and columns will allow the definition of the "chunks" that make up product architecture.

As an alternative approach to circuit identification, one can also consider the "reachability" information that is inherent in an adjacency matrix. To explain this concept, let us consider a simpler matrix A, as in Fig. 12.4. At first, the matrix can be simplified by iteratively pruning it of activities that do not have either any predecessor or any successor, which of course would be a necessary condition for being part of a circuit. Then, the simplified matrix A′ can be progressively elevated to powers $A'^2$, $A'^3$, …, $A'^n$ to identify circuits of the corresponding order. In fact, if matrix A′ contains information on the 1-step paths linking any couple of activities,

**(a)**




**(b)**

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| **A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **B** | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| **C** | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| **D** | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| **E** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F** | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| **G** | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

**Fig. 12.4** A simple DSM matrix with circuits to be identified

A=

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| **A** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **B** | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| **C** | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| **D** | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| **E** | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **F** | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| **G** | 0 | 0 | 0 | 1 | 0 | 1 | 0 |

A′=

| | B | C | D | F | G |
|---|---|---|---|---|---|
| **B** | 0 | 1 | 0 | 0 | 0 |
| **C** | 1 | 0 | 1 | 0 | 0 |
| **D** | 1 | 0 | 0 | 0 | 0 |
| **F** | 0 | 0 | 0 | 0 | 1 |
| **G** | 0 | 0 | 1 | 1 | 0 |

A′²=

| | B | C | D | F | G |
|---|---|---|---|---|---|
| **B** | 1 | 0 | 1 | 0 | 0 |
| **C** | 1 | 1 | 0 | 0 | 0 |
| **D** | 0 | 1 | 0 | 0 | 0 |
| **F** | 0 | 0 | 1 | 1 | 0 |
| **G** | 1 | 0 | 0 | 0 | 1 |

A′³=

| | B | C | D | F | G |
|---|---|---|---|---|---|
| **B** | 1 | 1 | 0 | 0 | 0 |
| **C** | 1 | 1 | 1 | 0 | 0 |
| **D** | 1 | 0 | 1 | 0 | 0 |
| **F** | 1 | 0 | 0 | 0 | 0 |
| **G** | 0 | 1 | 1 | 1 | 0 |

**Fig. 12.5** Using the algebraic "reachability" method to identify circuits

matrix $A'^2$ will provide information on the 2-step paths, and so forth. Therefore, if matrix $A'^n$ exhibits a non-zero value on the main diagonal, this indicates that there is an $n$-step path leading from the corresponding activity to itself or, in other terms, a circuit. Matrices $A'^2$ and $A'^3$ in Fig. 12.5 have non-zero values on their main diagonals, which show the existence of 2-step and 3-step circuits involving B, C and D.

This method tells us about the existence of circuits of different length that involve each activity, but does not help in identifying the activities that make up each circuit. This can be done through visual identification.

## 12.2.2 Managing Circuits and Iterations

When circuits have been identified, either visually or algorithmically, managers must cope with them. The case of wide circuits has already been mentioned, and managers will have to find a way to avoid iterations from occurring altogether, since these could severely disrupt project execution. Close circuits can be dealt with by following two approaches that enable the use of ordinary project management techniques.

The former approach is to recognize that close circuits call for a parallel execution of activities, with numerous and informal exchanges of information between the resources that are in charge of the same activities and—eventually—to the formation of single team that will be given the joint responsibility over the entire set of activities. This "concurrent engineering" approach suggests that, from a project management perspective, activities in a circuit simply be collapsed into a "macro-activity", without attempting to go deeper into the details of how it will be managed. When aggregating activities in a circuit, the resulting macro-activity will be likely to have a duration that is longer than the duration of the longest component activity, since interactions and iterations will probably require time. Management may therefore adopt rules of thumb in order to estimate this duration, such as "*we expect twice the time required by the longest component activity*". Concerning the effort required it is safe to hypothesize that, due to the parallelization of activities, the new macro-activity will require the joint presence of all resources originally planned for the component activities and for its entire duration (Fig. 12.6).

Collapsing a circuit into a single macro-activity is quite simple, but cannot always be done. Especially when dealing with activities that require a long time or involve many resources, management is likely to be wary of allowing a significant portion of the project to be self-managed by a large team, without any understanding of what occurs within. In this case, or if the firm wants to keep a tight control over the evolution of the project, another approach is required. This being the case, it is possible to "break the circuits" and then plan for a given number of iterations to occur. In other words (Fig. 12.7), if activities B, C, and D are coupled, the firm may at first decide to start B before D and D before C (thus allowing B to start without having information coming from C). The second step will consist in planning one or more corrective iterations, in order to adapt the results of D and B to the new information being generated by C. Looking at the project network, this means cutting (or "suspending") the arc from C to B in order to allow the sequence B → D → C. Then, this arc can be reapplied in order to represent the precedence relationships between the first and second iteration.

When following this approach, management will have to make educated guesses on the number of iterations that will be needed, and on the duration of the same activities in the iterations (e.g., "*we plan for two iterations to occur, with activity duration being cut by 50 % during the second one*"). The main decision to be made is then related to the sequence of activities within each iteration, and which arcs should therefore to be cut. In principle, one should cut the arcs that minimize the

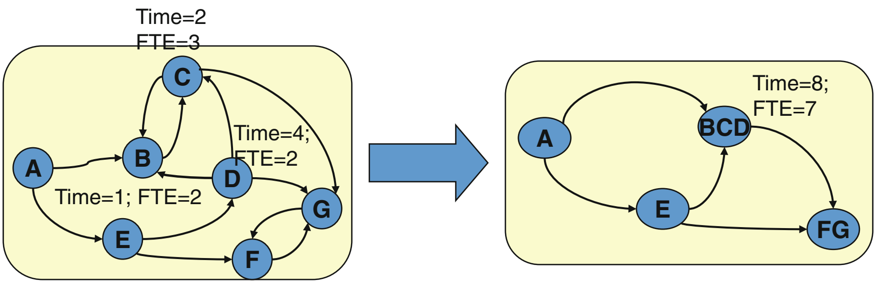



**Fig. 12.6** Managing circuits with macro-activities

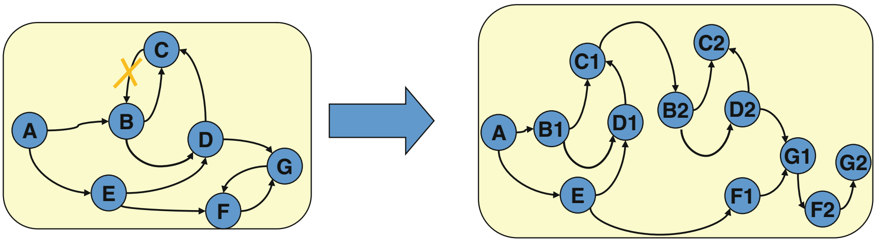



**Fig. 12.7** Managing circuits by breaking them, and then reiterating activities

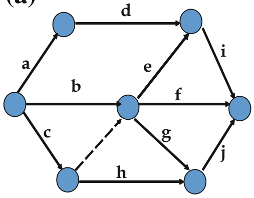
disruption to the activities that—because of that same cut—are forced to start without the benefit of having all the information they would need under hand. One should therefore be able to measure the amount and significance of information in each arc and cut the ones that score less on this measure. In some cases, managers may be able to perform an evaluation of this kind in quite a straightforward way, given their knowledge of the project. Should this not be the case, one can use a heuristic and assume that arcs carry the same information content. Activities can then be ranked depending on the net amount of information they produce. A simple proxy for this measure is to compute the difference between the number of outgoing and incoming arcs connecting each activity to the other activities belonging to the same circuit (i.e., not counting the arcs that connect outside the circuit). The activity with the largest such value will start first and—in order to allow this—its incoming arcs will be cut. Going back to Fig. 12.7, the scores for the three activities B, C, and D would have been B = 2 − 1 = 1; C = 1 − 2 = −1; and D = 1 − 1 = 0. So, activity B can start first, and this requires cutting arc C → B.

## 12.3 Project Scheduling

### *12.3.1 Scheduling with Infinite Resources*

Once the project has been analyzed and circuits solved, activities can be scheduled. In the simplest case, scheduling can be performed under the hypothesis of infinite resources, i.e., assuming that resources can be pulled into execute the project without any constraint. The *Critical Path Method**, or CPM is the most common approach. Just as a reminder, CPM can be considered to be a simulation of the project from the beginning to the end. It consists in defining an earliest starting time (EST) and an earliest ending time (EET) per each activity, with the difference between the two being equal to the duration of the activity. Each EST is defined as the largest among the EETs of the activities that—according to the activity network—are predecessors to it (in other words, you cannot start an activity until all of its predecessors have ended). The largest EET represents the duration of the entire project. Following Fig. 12.8a, the schedule can be defined by computing values of EST and EET by using a table (Fig. 12.8b) or by plotting a Gantt chart (Fig. 12.8c).

(a)




(b)

| Activity | Predec. | Duration | EST | EFT | LFT | LST | Slack |
|---|---|---|---|---|---|---|---|
| a | - | 2 | 0 | 2 | 9 | 7 | 7 |
| b | - | 4 | 0 | 4 | 6 | 2 | 2 |
| c | - | 3 | 0 | 3 | 3 | 0 | 0 |
| d | a | 2 | 2 | 4 | 11 | 9 | 7 |
| e | b, c | 5 | 4 | 9 | 11 | 6 | 2 |
| f | b, c | 1 | 4 | 5 | 13 | 12 | 8 |
| g | b, c | 2 | 4 | 6 | 8 | 6 | 2 |
| h | c | 5 | 3 | 8 | 8 | 3 | 0 |
| j | g, h | 5 | 8 | 13 | 13 | 8 | 0 |
| i | d, e | 2 | 9 | 11 | 13 | 11 | 2 |

(c)

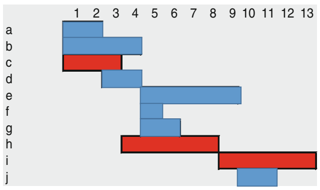



**Fig. 12.8** Using the critical path method (*CPM*) to schedule a project

After the project schedule is defined from the beginning to the end, it is possible to backtrack from the end to the beginning, computing latest ending times (LET) and latest starting times (LST) per each activity. The LET of an activity is given by the smallest of the LSTs among the activities to which the same activity is a predecessor (in other words, if you do not want to delay the entire project, you cannot allow an activity to end after any of its successors is—at the latest—due to start).

The difference $S_j = \mathrm{LST}_j - \mathrm{EST}_j$ is called "slack". A subset of the activities will have $S_j = 0$, which means that the activity cannot be delayed if not by accepting an increase in the duration of the entire project. These activities are defined *critical*. If instead $S_j > 0$, the activity could be delayed by this same amount without any disruption to the project. These activities are called *non-critical*. It can easily be shown that critical activities are sequential to one another, and therefore identify a "critical path" that determines the duration of the project.[3] Activities on the critical path have to be managed carefully, since any delay will have an impact on project duration. Similarly, if one wishes to reduce project duration, actions will have to be taken on the critical activities only. Conversely, delaying a non-critical activity up to the value $S_j$ will not determine any change on the overall project, while reducing its duration will not lead to any benefit.

Along with the Gantt chart, that shows the starting and ending time of each project activity, one can plot a loading chart representing resources usage. In a loading chart, each activity is represented as a rectangle whose base is the duration and whose height is the number FTEs employed. The associated effort will therefore be given by the surface of the rectangle. In a loading chart, rectangles representing activities are located on the time axis according to the schedule and piled on top of each other (of course, activities can be split in order to fill up any gaps). The envelope of the loading chart therefore shows the profile with which, given the schedule, resources are being absorbed at any time. Thanks to the loading chart it is possible to compute project cost, for instance in the case in which internal resources are available up to a given level, and external ones have to be called in when needed.

### *12.3.2 Project Crashing*

As mentioned earlier, activities might have been defined according to a standard and to an accelerated—or crashed—level. Project crashing is performed when project duration is not acceptable and managers want to decrease it. The most common way to do so consists in "crashing" activities on the critical path one at a

[3] In general, projects will have one critical path. It is however, possible to run into "degenerate" cases with two parallel paths of maximum duration, which are therefore both critical.

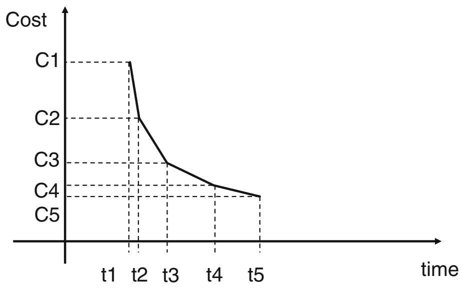



**Fig. 12.9** Project crashing and the resulting tradeoff curve

time. The critical path will have to be recalculated at each step, since the crashing of an activity may cause the critical path to change.

When determining the activity to be crashed, simple heuristic rules can be used. A popular one consists in using the Cost Change per Time Unit criterion, in which critical activities are ranked according to the following ratio

$$\frac{\mathrm{CC}}{\mathrm{UT}} = \frac{\text{crash cost} - \text{normal cost}}{\text{normal time} - \text{crash time}} \tag{12.4}$$

and then crashing the activity that exhibits the lower value, since it is the one that provides the greater return (in terms of time saved) per cost added.

By following this rule iteratively, a project manager can progressively move on to activities whose crashing is less favorable. The results at each iteration can be plotted on a graph, with time on the horizontal axis and total cost on the vertical one (Fig. 12.9). The resulting tradeoff curve allows choosing the solution that provides the firm with an acceptable combination of cost and time.

### 12.3.3 Finite Resources Scheduling

In many cases, resources are not freely available, but are limited. For instance, the project in Fig. 12.10 might have to be scheduled having no more than 5 FTEs under hand. Scheduling will have to cope with this new constraint, accepting that project duration be lengthened to some extent.

Finite resources scheduling can be performed in a number of ways. The simplest one consists in observing the loading chart that has been drafted in the infinite resources case, and then shifting the activities that correspond to the "peaks" that violate the resources constraint. This approach is manageable for relatively simple projects, in which constraint violations are not many. When the project becomes more complex, it is advisable to use heuristics based on "priority rules" (Elsayed 1982).

Scheduling a project with priority rules implies simulating its evolution from the beginning to the end, drawing the Gantt chart and the loading diagram step by

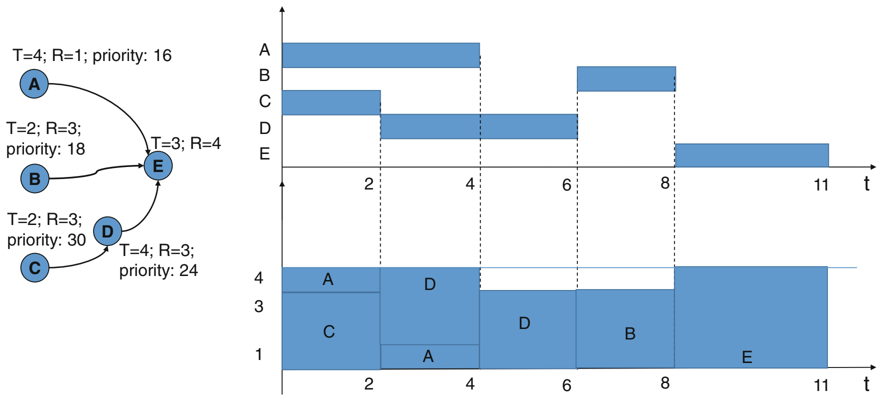



**Fig. 12.10** Using priority rules for project scheduling under finite resources

step. At each event, defined as the ending of one activity, one must list the activities that might start because precedence relationships allow them to. If the sum of the FTEs required by these "candidate activities" is less than the amount of resources available at that time, the constraint is not active and all activities may start without any delay. Note that the amount of resources available at a given time is computed as the difference between the number of FTEs available to the project and the amount of FTEs that are engaged by activities that are still under way. Instead, should the amount of available resources be insufficient, there is a conflict between candidate activities. A priority level is then computed per each of these activities (bearing in mind that a candidate activity qualifies if precedence constraints enable it *and* if it the number of FTEs that it requires is not greater than the available ones). The candidate activity with the highest priority will start and engage the resources it requires. The procedure is iterated among the remaining candidate activities until no further activity can start. The scheduling process will then shift to the next event (i.e., to the ending of an activity that is closest in time), and so on. Figure 12.10 provides an example of this process in a simple case.

With finite resources scheduling, the concept of "critical path" loses its meaning. One might try to identify a critical path by backtracking from the end of the project and progressively looking for the upstream activity that determines the EST of a downstream one. In the case of infinite resources, this relationship would only be due to precedence relationships (i.e., you can start critical activity X after all of its predecessors have ended, and the predecessor that ends the last is critical as well), thence the implication that critical activities form a path. In the finite resources case, an activity's EST could also be due to the progressive freeing up of resources. In other words, with limited availability of resources, you can start activity X when predecessors have ended *or* when a completely unrelated activity that was saturating resources ends. Therefore, the activation of one activity at the end of another one does not imply a connection in the activity network, and the two activities therefore might not lie on a same path. Moreover, the connection between the ending activity that frees up resources and the subsequent one does not depend on the network structure, but on the specific schedule that has been chosen. Therefore, one cannot formally speak about critical activities and critical paths in finite resources scheduling. From a managerial perspective, it might nonetheless make sense to label the set of activities that are critical because of any of the two reasons outlined above, since these will have to be managed carefully, if delays to the project are to be avoided.

A wide range of priority rules has been developed, and the choice depends on the activities that the project manager wants to bring forward. Before describing individual priority rules, it is, however, important to notice that the priority of an activity is not to be computed by looking at that activity in isolation, but at the impact on the overall project if the activity is placed at the top of the priority list, thus enabling the launch of its dependent activities. In other words, the priority of an activity should be computed by looking at the paths that are originated from it and—in the common case that more than one path is originated—to the one that maximizes its priority. With this principle in mind, it is now possible to discuss the following main priority rules. Other priority rules, which generally represent linear combinations of the ones listed below, have also been proposed in literature (Elsayed and Nasr 1986).

- Activity Time (ACTIM) is one the simplest rules. Priority of an activity is given by the maximum—computed over all the paths originating from that activity—of the sum of the durations of the activities belonging to the path. If one thinks in terms of the loading diagram, priority is given to the rectangles representing activities that have a wider base and take up more time.

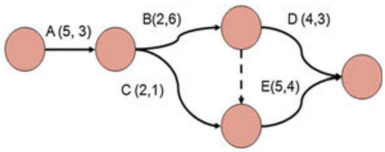
$$\mathrm{ACTIM}\ (A) = \max_j \sum_{i=1;i\in j}^{n} d_i \tag{12.5}$$

- Activity Resource (ACTRES) states that priority of an activity should be computed by looking at the product of duration and resources usage of the activities in the path. Looking at the loading diagram, priority is given to rectangles that take up a large surface.

$$\mathrm{ACTRES}(A) = \max_j \sum_{i=1;i\in j}^{n} d_i * r_i \tag{12.6}$$

- Resources Over Time (ROT) looks at the ratio between FTEs and duration. On the loading diagram, priority is therefore given to “tall” rectangles.

$$\mathrm{ROT}(A) = \max_j \sum_{i=1;i\in j}^{n} \frac{d_i}{r_i} \tag{12.7}$$




ACTIM (Activity time)

$$ACTIM\ (A) = \max\{5+2+4,\quad 5+2+5,\quad 5+2+5\}$$

ACTRES (Activity resources)

$$ACTRES\ (A) = \max\{3\cdot 5+6\cdot 2+3\cdot 4,\quad 3\cdot 5+1\cdot 2+4\cdot 5,\quad 3\cdot 5+6\cdot 2+4\cdot 5\}$$

ROT (Resources over time)

$$ROT\ (A) = \max\left\{\frac{3}{5}+\frac{6}{2}+\frac{3}{4},\quad \frac{3}{5}+\frac{1}{2}+\frac{4}{5},\quad \frac{3}{5}+\frac{6}{2}+\frac{4}{5}\right\} =$$
$$= \max\{4.35, 1.9, 4.4\} = 4.4$$

**Fig. 12.11** Computing priorities in a simple project network

The example in Fig. 12.11 shows the calculation of priorities for activity A of a simple network.

The previous discussion has covered the case of projects with resources of a single type. However, it is quite common for projects to involve resources of different types, who cannot be substituted with one another (e.g., hardware engineers and software developers). When dealing with multiple resources, it is customary to perform finite resources scheduling for the resource type that is the bottleneck to the project, i.e., for which the ratio between required resources and available ones is the highest. In fact, by scheduling on a bottleneck resource, the project will last longer and activities will tend to spread out in time. Therefore, the non-bottleneck resources will be even less likely to cast a constraint on the project. The easiest way to identify the bottleneck resource is to quickly schedule the project under the infinite resources hypothesis, and then look at the usage ratios of each resource type.

In other cases, resources are pooled across a number of different projects. Multiple-project scheduling is a very difficult task to perform from an optimization perspective. It is therefore possible to recommend simple heuristics, based on the assignment of priorities $P_j$ to the projects. Specifically, three approaches can be considered.

The simplest approach is to make an *ex-ante* split of the available resources pool among the different projects, based on their priority and their resources usage, and then schedule them independently from one another. So, if the number of available resources is $R$ and the effort required by each project is $E_j$, each project $j$ will be assigned a number of resources given by

$$R_j = \frac{E_j P_j}{\sum_{j'} E_{j'} P_{j'}} \tag{12.8}$$

Another approach consists in ranking the projects according to priority, and then scheduling projects sequentially, starting from the highest-priority one. Then, the second-highest ranking project will be scheduled, based on the resource availability that has not been used by the previous project, and so on. When following this approach, the projects tend to follow a sequence, though with some overlap. The first project will effectively be scheduled with hardly any resources constraints. The second project will be "squeezed" in the capacity that is left over by the first, and will accelerate when the first project ends, and so on.

Finally, one can consider the entire set of projects as a single and large project that can be scheduled with the usual priority rules. When using these rules, priority of an activity will be multiplied by the priority of the project the activity belongs to. This tends to allow parallel execution of projects, though the ones with higher priority will be favored and tend to start and end earlier.

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# Chapter 13
# From Market Research to Product Positioning

Starting with this chapter, we make a deep plunge in the product development process with a very practical approach, exploring methods and tools that may support development teams in their work. The coverage of the development process will be limited to the first phases, at least up to the point where general-purpose methods can be applied, irrespectively of the industry and of the technology that underlies products or services. The subsequent phases of product development, which focus on the detailed design of products and processes and on product industrialization, will therefore be left aside.

As discussed in Chap. 11, the first phase of the product development process is concerned with product planning. During this phase, the firm must at first develop a clear understanding of the market, of customer needs, and of competitive offering. Then, it must come up with a high-level description of the product (i.e., a *product brief*) allowing its positioning in the market space. At this point, the firm will be able to make preliminary forecasts of demand and develop a first business case to study its profitability. The current chapter follows these early steps in product planning, while Chap. 14 will deal with the remainder of this phase.

## 13.1 Customer-Driven Product Development

In developing these topics, we concentrate of a market-pull development process, in which the firm intends to deliver an incremental innovation to an existing market. In this case, firms generally follow what is called a *customer-driven product development* approach, which spells out that the main initial focus should be on understanding customer needs, and the rest of development activities should gravitate around the satisfaction of these needs. This mainstream approach has been extremely popular since the '90s and is still followed today.

The customer-driven approach might, however, not be suitable for radically innovative products, since in this case markets are yet non-existent. Customer needs might therefore be latent and tacit, and potential customers unable to recognize and articulate them. In the case of radical innovations, which are generally based on technology push, product development must instead focus on matching the features



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_13

that are technically attainable to specific and generally latent needs of potential application areas and market segments.

Moreover, the rationality that is inherent to the customer-driven approach might make it inapplicable to so-called *design-driven* innovations (Verganti 2009). In these cases, success is based on a tacit interplay between the cultural and "emotional" content proposed by firms and customers' perceptions and tastes. For instance, in the case of fine mechanical watches with multiple "complications", customers are willing to pay significant amounts of money for an object that is at the same time a status symbol, the fruit of high-end technology and engineering skills, as well as an object of art. Similarly, most new products in the automotive industry can be associated to design-driven innovations, since aesthetic and cultural aspects have a role that is comparable—if not even superior—to vehicle performance and satisfaction of functional needs.

Customer-driven product development can be applied in both cases of products aimed at consumer markets (Business-to-Consumer, or B2C) and at corporate markets (Business-to-Business, or B2B). The two cases are clearly quite different, with the former being more complicated to manage. In the case of B2C, producers have very few contacts with their final customers, who are many and are separated by many layers of intermediaries as well as by geographical distances. This makes it difficult to go beyond a shallow understanding of customers' needs and wants, and of the purchasing process they follow.[1] In addition, consumers buy products because of a number of tacit criteria and aspects, many of which highly emotional. Therefore, consumers' purchasing process will be much richer and complex than the generally rational analysis of technical performance and features that is often made by businesses, and will also be heavily influenced by marketing strategy, the availability of complementary products, and so on. As it has been mentioned in Chap. 4, the complexity of the purchasing process makes it impossible for consumers to carry out a rational and informed evaluation of competing products. In this context, brands play a major role by encapsulating and communicating a given set of tradeoffs that is coherent with the brand, so that customers may choose among competing products without actually having to learn about underlying technical details and compare them.

Based on the above, this chapter will discuss market research methods and tools that are typically used in the context of consumer product development. This does not rule out that they may be useful for B2B products as well.

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[1]As an example, one can think of the lack of communication between a producer of toothpaste, and the millions of people who daily purchase this product, and then compare it to the continuous interchange of information between the producers of specialized machine tools and their few and well-known customers.

## 13.2 Defining the Market

The very first step in trying to understand the market lies in defining the market itself. This is not a trivial exercise, since decisions at this stage are not straightforward and can lead to important implications later on. The definition of a market implies the drawing a boundary between what is "in" that market (and must hence be considered when performing competitive analysis) and what is "outside" (and will therefore be neglected).

It should also be stressed that there is a difference between the concept of "market" (which represents demand, composed of customers) and of "industry" (which represents offer, which is instead made up of suppliers). While this difference appears to be obvious in theory, it is always easy to conflate the two terms in practice. With this in mind, it is possible to list a number of possible criteria that can be used to define and circumscribe markets.

- **Econometric criteria**. Economists generally state that markets are defined by a set of substitute products, defined as products for which cross-price demand elasticity exceeds a given threshold.

$$E_y(x) = \frac{\Delta Q_y}{Q_y} \bigg/ \frac{\Delta P_x}{P_x} \tag{13.1}$$

  In other terms, two products belong to the same market if a relative price increase for product *X* leads to a sufficiently large relative quantity increase for product *Y*. Alternative econometric criteria include measuring the correlation between price variations of products, which is an indicator of competitive dynamics, or evaluating whether cartels could be established, leading to monopolistic pricing. These criteria are widely used by economists engaged in both research and practice (for instance, when working on antitrust cases, a preliminary step usually consists in developing an objective definition of the market). However, it is not trivial to define thresholds for these econometric indicators in such a way that it makes sense for market research purposes. In fact, if one considers these indicators, any two products might bear *some* degree of cross-price demand elasticity and of price correlation.
- **National statistics offices** often allow an indirect definition of markets by looking at the related industries. In all countries, producers are classified by national statistics offices according to a hierarchical code[2] (e.g., NAICS in North America, NACE in Europe, and so on). Following these definitions is quite appealing because of the plentiful availability of official data that is based on

[2]A hierarchical coding of economic activities is composed by a string of characters, with the first ones representing the higher-level classification and the subsequent ones representing finer subdivisions whose meaning depends on the former. So, for instance, NACE C13.9.3 defines "manufacturers of carpets and rugs", with C representing all kinds of "manufacturing", C13 the "manufacture of textiles", and C13.9 the "manufacture of other textiles".

these classifications (e.g., sales by industry *X*, investment made by industry *Y*, purchases made by industry *Z* from industry *K*). However, these classifications are often flawed, since it is common for individual firms to be diversified (i.e., a firm may be registered in industry *X*, but also produce goods related to industry *Y*), or to change their actual focus over the years, without bothering to change their registration code. Moreover, coding systems generally are unable to correctly represent the industries behind highly innovative products, whose very existence has not yet been captured by the statistics offices.

- **Geography**. An obvious criterion for defining markets is related to geography. The concept of geography being used in this context is generally extended to any kind of barrier that can insulate one area from another one, preventing arbitrage mechanisms that would lead to a single market. Geographical distances can matter, of course, but also can tariffs, differences in regulations, or differing consumer tastes, which are highly product specific. Therefore, firms may recognize the existence of a single European market for consumer electronics, but not for building materials, which are specific to each country and its architectural traditions.
- **Product similarity**. Since products pertain to the same market when they are substitutes, product similarity can be an indicator of potential substitutes. This criterion lends itself to two different interpretations. One is technical similarity (e.g., one might consider a market for “railway transportation” that encompasses all types of trains), and the other is similarity in the needs being satisfied (e.g., the market for “high-speed transportation” that includes short-range airways and high-speed trains).
- **Switching behavior**. This criterion can be used for consumables and use data collected from customer panels. Two products will be substitutes and therefore belong to a same market if customers often switch from one to the other, but not if customers remain loyal to one. For instance, biodegradable laundry soap can be considered to have a market that is independent from normal detergents if customers who purchase this kind of soap always do so, and vice versa.
- **Demographic criteria**. Demographic criteria define segments of the population that can be relevant to a product offering. For instance, when developing a two-seat sports car, one might consider a market of “young, urban, affluent drivers”. Demographic criteria can include age, profession, education, household structure, income, wealth, lifestyle, etc. In some cases, these segments are defined purposely for the product. In other cases, they can coincide with clusters that are uncovered independently by market research firms when performing general surveys of the population.

In practice, firms will often define markets by operating on two tiers, with a broader definition of “market” and a narrower definition of “segment”.[3] The

[3]For instance, a firm may define its market as the “market for urban mobility” and develop a product for the segment of “city bicycles”. Another firm may instead define its market as “bicycles” and operate on the segment of “road bicycles”.

definition of markets and segments depends on the type of innovation the firm is attempting to introduce. It will be narrower in the case of incremental innovations, and broader in the case of radical ones, that might disrupt existing schemes.

## 13.3 Capturing the Purchasing Process

Once the market has been identified, firms must try to understand the purchasing process followed by customers. In fact, it would be very difficult for a new product to sell well, if this process has not been correctly understood. In the case of B2C markets, the purchasing process is somewhat simpler than in the case of B2B, where decisions involve a number of different actors. However, consumers' purchasing decisions do not follow a formalized and rational process, and this makes it quite difficult to achieve a deep understanding of elements that might determine product success or failure.

The tacit nature of consumers' purchasing behavior has induced marketing scholars to use results from the field of cognitive psychology in order to gain a better understanding of this phenomenon. Among the many contributions available, this discussion will be limited to presenting an adaptation (Tapp 1984) of the "lens model" of perception (Brunswick 1944), due to its simplicity and effectiveness. The basic idea behind this model is that the decision a customer takes when she chooses a specific product among competing alternatives and purchases it, is quite complex. In fact, consumers make this kind of decisions without having a clear, objective and deterministic view of their needs and of the way with which product features can fulfill them. Especially considering the latter, the dimensionality of the problem can become very high indeed, and prevents customers from making a rational choice based on technical data.[4] Human beings are known to be unable to cope with such multidimensional problems, and therefore use a process called *perception* in order to aggregate tacit elements and "hard" raw data in a hierarchical way, until the problem becomes manageable.[5] Therefore, consumers will "perceive" the mass of information attached to a product by abstracting it in a space of limited

[4]For instance, imagine a person having to choose a digital camera in a store. Dozens of models are on display, each of which carries an information card that lists a dozen features or so, together with price. It would be unlikely to see that person make a choice by pulling out a sheet of paper, writing down a shortlist of cameras that exceed given thresholds, and then ranking them based on a weighted score of performance indicators.

[5]For example, reading this book means that your eyes are stimulated by light patterns corresponding to the characters on the page. A *perceptual process* allows you to isolate the characters, understand them, aggregate them in words and—hopefully—understand their meaning. The perceptual process is not innate and has to be learned, and the information thus processed can be managed only in relation to pre-existing knowledge (think about the difficulty in reading a book on a familiar subject, written in an unfamiliar language, or vice versa).

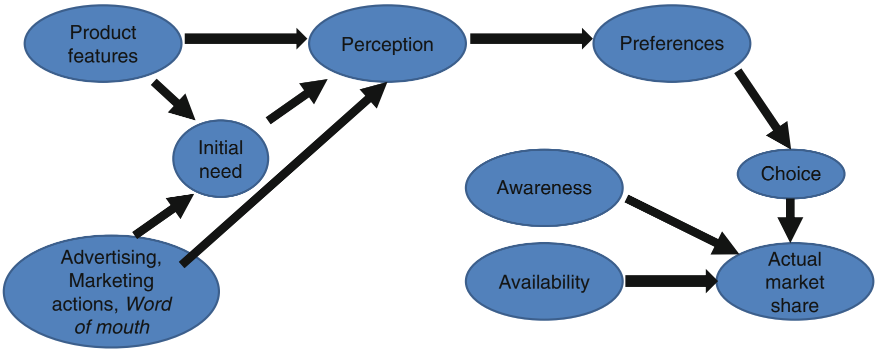


**Fig. 13.1** Purchasing as a perceptual process

dimensionality, defined by high-level needs and features,[6] in which they will make their purchasing decisions.

The perceptual phenomenon does not occur as a single event in time, but evolves along with the purchasing process in which the consumer starts thinking about the possibility of buying the product and ends up choosing a specific model and paying up its price. By linking these two aspects it is possible to outline the overall process as in Fig. 13.1.

At the beginning, a potential customer has not yet developed a decision to purchase the good, and is not even investigating this possibility (e.g., imagine someone who is not thinking about buying a new car, and casually sees a new car model on the street, or views a web banner advertising its launch). The first stage of the purchasing process brings this potential customer to the stage of feeling the need and being interested in purchasing the good. This can occur because of features that are inherent to the product (e.g., the new car models might have an outstanding fuel efficiency) and because of influence cast on the consumer by other parties. These can convey both objective information on the product (e.g., mileage of new cars) as well as other types of information (e.g., the association of new cars to an attractive lifestyle). Such an influence can be defined as either *external* or *internal* to the market. External influence includes advertising and other media, such as articles in the press or product reviews on specialized websites. Internal influence has to do with imitative effects, which can be due to explicit word of mouth (e.g., a friend who buys a new car and tells wonders about it) as well as to tacit emulation (e.g., new cars are bought by many people and become fashionable).

At this stage, the consumer has now become an active decision maker and information seeker, and the perceptual process is at its foremost. At the end of this process, the consumer will have defined the *perceptual space* in which she can position competing products, according to the degree with which these seem to

[6]For instance, the digital cameras of the previous example may be perceived and assessed by consumers according to two dimensions, such as "technical performance" and "ease of use".

allow the fulfillment of her needs. Eventually, this leads to the generation of preferences for each competing product. This will enable her to choose whether to purchase the product or not, in the former case deciding on which product to buy, and in the latter case deciding whether to abandon the idea or simply delay the decision. If one considers a population of consumers and the choices they may make at this stage, these decisions define the *potential market share* of a product, i.e., the fraction of consumers who—given their willingness to buy a product—would choose model *X* over competing ones.

The actual market share will be a fraction of this potential, since it will be abated by a factor called *awareness* (due to the fact that not all potential consumers might be made aware of the existence of the product) and *availability* (since not all of them will actually be able to buy the product because of distribution choices). When thinking in terms of corporate functions and processes, potential market share is clearly the responsibility of the product development process, awareness of marketing strategy, and availability of distribution strategy. An integrated view of the whole process should, however, lead a firm to bring all of these factors under the responsibility of the product development process.

## 13.4 Modeling Consumers' Perceptual Space

The perceptual process is not only quite complex, but also tacit and—to some extent—unconscious, which implies that firms cannot model it by simply asking consumers about it.[7] The most common approach for capturing the process consists in performing market research actions that allow the modeling of a hierarchy of *customer needs* (in the case of B2C products, we can use the term *user needs* interchangeably, though this would not be acceptable if customers were distinct from users, as is often the case for B2B products).

The word "need" being used here is very important, since it has to be stressed that—while firms tend to think in terms of product features and performance—customers think in terms of their own needs and of products' capability of fulfilling them. As a matter of fact, features and performance indicators are not only technically quite alien to consumers (e.g., who can really understand the meaning of "in car model *X*, noise at cruising speed in the front seats is 65 dB"?), but can also be misleading if they are not linked to specific needs (e.g., in the previous case, the underlying need would probably be "I want to chat with passengers without having to raise my voice").

[7]Think about asking a friend who has just bought a product to tell you about the precise actions and thoughts that led her from the initial stage of "I wasn't thinking of buying X" to actually making the purchase. What differences would there be between X being a car, a smartphone, or toothpaste?

### *13.4.1 Kano's Model of Needs Satisfaction*

Given that product attributes should not be managed in their own right, but in relation to customer needs, it is at first important to realize that needs are not all equally important. It is therefore worthwhile to introduce a short discussion on Kano's (1984) classification of customer needs and of the degree with which product attributes fulfill them. According to Kano, each need and corresponding product attribute can be classified by looking at the way with which the degree of implementation of the latter leads to the satisfaction of the former. This relationship can be mapped on a two-dimensional map, as in Fig. 13.2.

Each need and product attribute can then be represented as a function on this graph, leading to distinct types of needs/attributes.

- **Must-be attributes/basic needs**. Customers take the fulfillment of these needs for granted, together with the presence of the associated attributes. Therefore, the former do not generate satisfaction when met, while dissatisfaction emerges if they are not fulfilled. For instance, customers expect bottles not to leak. A customer would clearly be dissatisfied by a leaky bottle, while buying a bottle that does not leak does not generate any satisfaction. Since customers expect these attributes, it is unlikely that they will be able to express them to an interviewer during market research. As shown in the figure, these attributes and needs can be represented as non-decreasing functions in the bottom quadrants (SW and SE) of the graph.
- **Attractive attributes/"delighters"**. Customers do not usually expect the satisfaction of these needs and the presence of the related attributes. Implementing the latter generates satisfaction, but no disappointment is caused in the opposite

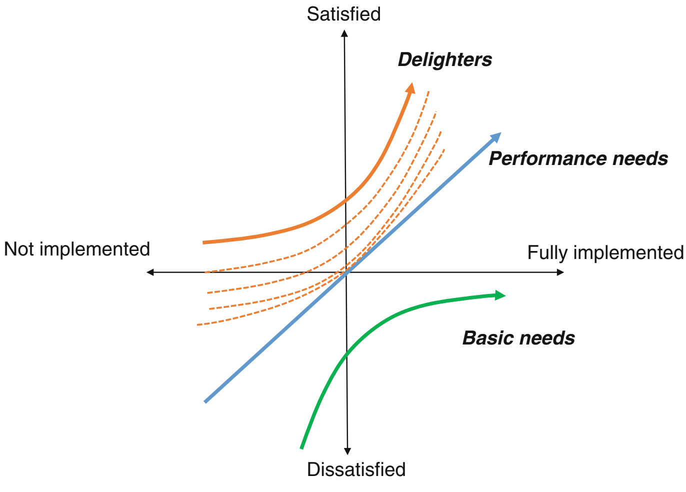


**Fig. 13.2** The Kano model links the implementation of attributes to the impact on satisfaction of customer needs

case. For example, a guest in a hotel may not expect, but greatly appreciate, a voucher for a complimentary dinner during a stay that occurs on her birthday. Also in this case, and being unexpected, it will not be easy to elicit these needs and attributes through market research. Concerning the graph, these attributes and needs can be represented as non-decreasing functions in the top quadrants (NW and NE).

- **One-dimensional attributes/performance needs**. In this case, by not implementing these attributes and the resulting non-satisfaction of a need will generate disappointment, while their implementation will lead to the fulfillment of the need and satisfaction (for instance, the need to minimize a car's operational costs is directly linked to fuel efficiency). Customers and companies are usually quite aware of these attributes and needs and are able to articulate them. The relationship between implementation and satisfaction is a non-decreasing function that straddles the SW and NE quadrants of the graph. Figure 13.2 shows a family of such curves, in which it is made clear that the slope is not necessarily constant, since saturation effects may occur beyond a given limit both on the right-hand and left-hand sides of the graph.
- **Indifferent attributes** do not directly affect customer satisfaction. These attributes are related to technical features that customers are not able to assess, even though they might be essential to the product. In the graph, they are located close to the $x$ axis.
- **Reverse attributes**. These attributes refer to features that not all customers might appreciate. For instance, in the case of high-tech products, some customers might prefer basic and easy-to-use models to high-end and complicated ones. In this case, the curve (which has not been drawn in Fig. 13.2) would be non-increasing and straddle the NW and SE quadrants.

At any given time, firms will usually compete with each other by ensuring their products comply with must-be attributes, will try to have an edge on their competitors on "one-dimensional attributes", and try to differentiate themselves by providing some "attractive attributes". As time goes, by, customers will become more demanding and tend to get used to features and take them for granted. Therefore, what could have been considered an "attractive attribute" in the past, may be considered to be a "one-dimensional attribute" today, and become a "must-be" in the future.

## *13.4.2 Needs Hierarchies in the Perceptual Space*

The Kano model leads to a ranking of needs, distinguishing among ones that must necessarily be addressed and other ones that may be considered to be optional. As previously discussed, customers will process these needs according to a perceptual process, in which they make a hierarchical aggregation of multiple elementary needs into a smaller number of progressively more abstract ones. In general, the following three needs levels can be considered:

- *Tertiary needs* are the most elementary ones, are usually quite numerous (tens or even hundreds for complex products), and can usually be elicited by interacting with customers (examples are "*I want to fit a lot of baggage in the trunk of my car*", "*Loading and unloading heavy items in the trunk of my car must not require too much effort*", etc.).
- *Secondary needs* are an aggregation of tertiary needs, achieved by clustering tertiary needs. A product can usually be defined in terms of 10–20 secondary needs, which are detailed enough that they can be effectively communicated and discussed with customers (e.g., "Capacity and accessibility of the trunk" is a concept that is quite unambiguous and easy to grasp).
- *Primary needs* are an aggregation of secondary needs that defines the perceptual space in which products are tacitly represented and compared during the purchasing process. Primary needs are usually no more than 2–4 (e.g., a car might be perceived according to the two dimensions of "performance" and "convenience", where the secondary need "capacity and accessibility of the trunk" might be one of the elements that make up the concept of "convenience"). At this level, the perceptual process is tacit and unconscious. Therefore, this final aggregation can be studied indirectly, by asking customers to provide clues about the affinity they perceive between secondary needs.

The following part of this section will provide an overview of the techniques that can be used to develop this needs hierarchy.

### *13.4.3 Eliciting Tertiary Needs*

Tertiary needs constitute a long and exhaustive list of elementary requirements that users relate to the product. In the case of complex products, tertiary needs can be associated to a set of different *use cases**, i.e., interactions between user and product that allow the achievement of specific goals.[8] In order to elicit such needs from users, it is possible to directly interact with groups of consumers, following a variety of approaches.

- **Focus groups*** are made up of a small number of consumers, who are asked to discuss the product and their needs under the guidance of a facilitator, while an analyst documents the proceedings, generally using audiovisual footage. Focus groups usually involve 8–12 participants, so to ensure that group dynamics is lively enough and that each individual has enough chances to contribute. The main objective of a focus group is to collect the widest possible collection of

[8]For example, "cruising on the motorway", "parking the car", "loading the car" may be considered to be use cases associated to a car.

tertiary needs. Therefore, focus groups are not assembled looking for representative samples of the population, but trying to create the widest variety possible, involving both generic users and *lead users**.[9] Given the time required to attend a focus group, there may be segments of the population who might be unwilling to participate, and therefore go underrepresented.

In a focus group, the facilitator must be able of guiding the discussion in a way that most of the group's experience and insight is brought to the surface. Moreover, the facilitator has the role of bringing participants back to the objective of generating tertiary needs, should the discussion fall astray. To this purpose, he must have a clear understanding of the differences between solutions, specifications, performances, outcomes, and needs.[10]

Focus groups are quite expensive activities, given the costs associated to logistics and the effort spent by facilitators and analysts. It is therefore quite common to progressively add new focus groups to the market research process, and as long as the number of new tertiary needs uncovered at each step exceeds a given threshold. The process ends when the marginal contribution becomes too small.

- **Direct observation** is a variant of focus groups. While the latter are generally played out around a pure discussion format, this technique brings participants around a product or a prototype, and the facilitator stimulates discussions around the actual interplay between users and product. This can be helpful, since users with a non-technical background might find it difficult to articulate verbal expressions on their usage of the product, but feel at ease if they can simply show "how things are done" or "why this doesn't fulfill my needs".
- **Scenario of use** is a variant of the previous method. Instead of an open-ended discussion around the product, it requires participants to play roles and act according to a script (e.g., "Mr. and Mrs. Black and the kids, loading the car at the supermarket on a Saturday morning"). Role-playing makes the participants concentrate on use cases that are considered to be relevant and—at the same time—it can lead participants to stress issues that lend themselves to comic outcomes, thus going deeper in their analysis.

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[9]*Lead users* (von Hippel 1986) are customers who face needs that will become prevalent much earlier than the general population, and might also contribute with original solutions to solve the need. Following a more extended meaning, a lead user may be a user whose particularly intense usage of the product amplifies her perceived needs (for instance, a taxi driver can be considered to be a lead user when it comes to driving a car in an urban environment).

[10]For instance, a focus group participant might say she needs her smartphone to be equipped with a low-power chipset. Since this is not a need but a technical solution, the analyst should ask her why. The customer's answer might be that she needs her phone to have 250 h of standby time between recharges but—again—this is not a need, but a performance specification. So, the analyst will have to ask a second "why", to which the user might answer that she basically wants her phone battery to last over a weekend, should she forget to bring the charger with her. This can finally be considered to be a need, since it clearly shows an *outcome* (i.e., a job to be done) that might satisfy the user, regardless of the technical means with which it is achieved.

- **User trials**. With this technique, groups of users are asked to perform a sequence of activities on products or prototypes, and are interviewed after the session. Lack of direct observation of the user trial places the users at ease and ensures spontaneity. At the same time, it greatly reduces the richness of the information captured.
- **Product-in-use** consists in the direct observation of the product being used in real settings by unsuspecting people, possibly with the support of audiovisual recordings. Due to privacy issues, there are obvious limitations to the types of products and use cases that can be observed. The technique is valuable, especially for uncovering wrong "use modes" that would generally go unreported.
- **Customer diaries**. Customers (often termed *beta testers*) are provided with products or prototypes and are left free to use them for a period of time. In exchange, they are required to provide feedback to the firm. The information thus gathered is generally quite shallow and is limited to finding faults, rather than uncovering needs.
- **Participative techniques**. Customer involvement in the development process can also be deeper than the elicitation of tertiary needs. Participative design techniques are variations of focus groups, in which customers' creative input is sought. Customers are therefore stimulated to provide ideas, solutions and associations between the product and concepts pertaining to everyday life.

The techniques listed above allow firms to gain a deep understanding of the needs arising from the consumers who volunteer to take part in these activities. However, these techniques are fairly costly to run, and involve only a tiny fraction of customers. Recently, the diffusion of the Internet and the emergence of data analysis techniques able to operate semantic analysis and to sift through large datasets of unstructured information have provided firms with new ways for understanding customer needs. Thanks to these tools, firms can automatically analyze both internal data sources (e.g., databases recording customer claims) and external ones (e.g., comments posted on social networks) to understand customer needs. Firms' presence on the Internet, be it on proprietary pages or on open forums, can therefore be seen not only as an advertising channel, but can also allow two-way communication, providing important information for product development.[11]

In some cases, the product development team may need to achieve a broader and deeper understanding of customers and of their needs. This is particularly true when designing radically innovative products or business models, for which it is difficult to start from an existing offering. In these cases, the team can widen its perspective, and attempt to take into account a comprehensive view of customers, their inclinations and problems to be solved. Empathy maps (Gray et al. 2010) are a simple and powerful tool that allows generating this insight in a structured way. The six

[11]The topic is still under development. Readers may refer to Kozinets (2002) for the application of ethnographic techniques to online communities (also termed *netnography**). For a discussion on the benefits and the limitations associated to using information gleaned from social media in the product development process, readers may refer to Roberts and Candi (2014).

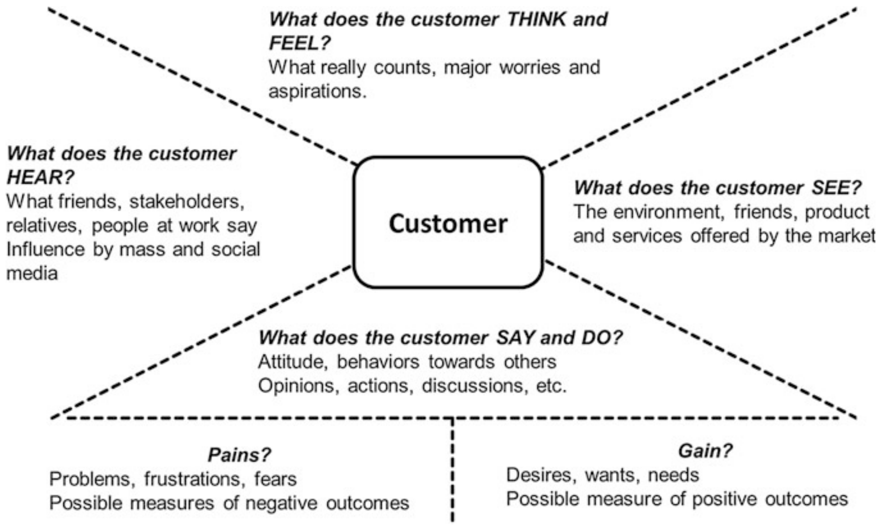


**Fig. 13.3** Structure of an Empathy Map

areas in an Empathy Map, whose meanings can be intuitively understood by looking at Fig. 13.3, can be explored and filled in either by direct customer involvement, or by interviewing panels of experts.

Finally, firms can start an intense interaction with consumers, so that the latter may provide opinions, point to emerging trends, react to preliminary information on new products or product concepts, suggest improvements, and even conceive and design new products (Fuchs and Schreier 2011). As shown in Fig. 13.4, these interactions can be classified according to the responsibility that the firm decides to

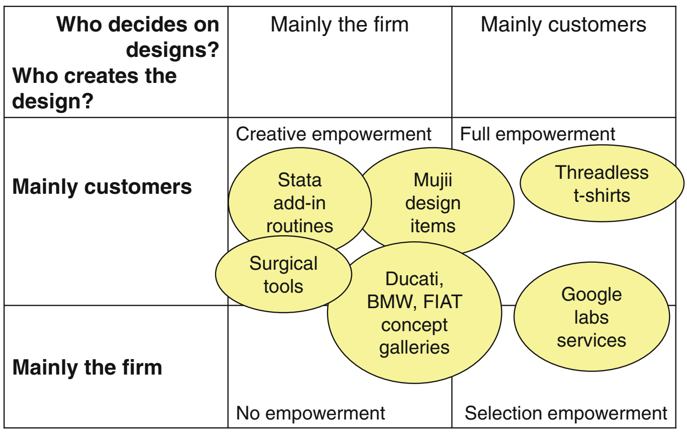


**Fig. 13.4** The different forms of active customer involvement in product development

share with its customers in the generation of ideas and designs, and in the selection of the products to be launched. Moreover, and depending on the kind of product, this involvement can cover the overall product, non-core aspects (e.g., creating and selecting external décor) or ancillary features (e.g., creating and selecting advertising campaigns).

### *13.4.4 From Tertiary to Secondary Needs*

Secondary needs are aggregations of tertiary needs into a manageable number of higher-level items that are still easy to treat and discuss explicitly. In most cases, the aggregation can be directly performed by the development team, by clustering similar tertiary needs. A common technique consists in writing down each tertiary need on a card or sticky note, and then clustering the cards on a whiteboard until a satisfactory solution is found. This method does not require much effort, but has the drawback of using a perspective that might not be the same as the customers'. However, this is generally not seen as a big issue since—at this level of aggregation—the two perspectives may not differ much from one another.

In any case, and in order to avoid this risk, the development team may involve a small sample of consumers and ask them to individually perform the same clustering exercise. Then, by counting the % of times that need $i$ is matched with need $i'$, one can come up with a similarity matrix between each pair of needs, and then using hierarchical clustering[12] to obtain an objective definition of secondary needs.

Once clusters have been created, the development team will have to come up with a concise verbal description of the secondary need, such that the underlying tertiary needs are well captured and represented.

### *13.4.5 From Secondary to Primary Needs*

After the list of secondary needs has been drawn, the final step consists in aggregating them into a limited number of primary needs, or *perceptual dimensions*. Attempting to do so by clustering supposedly "similar" items—as has been suggested for the previous step—can be highly misleading since, at this stage, the perceptual process is tacit and unconscious. Moreover, it would not be wise to perform this study on a limited and possibly non-representative sample of consumers.

[12] We have chosen not to provide explanations for basic multivariate analysis techniques in this textbook. We therefore suppose that readers are either already familiar with them, or they will be able to refer to specialized sources (e.g., Johnson and Wichem 2007) to gain the necessary knowledge of these techniques and of the way they can be used.

Therefore, tacit primary needs must be identified by performing a survey on a broad and representative sample of consumers, using a questionnaire that will provide important insights on a number of other elements as well. In general, a market research *questionnaire** will contain a number of sections that can collectively lead a firm to a better understanding of the market, of customer needs, and of the way with which customers perceive competing products. Without going into the details of good questionnaire design,[13] the main sections of such a questionnaire will include the following:

- **Demographics**, which capture descriptive variables associated to the respondent, and that can be relevant for the analysis being carried out. Examples of such variables include age, gender, income, etc. These variables can also be used during the validation of the dataset, in order to check whether the sample fits with the general population or, conversely, whether the surveying process has led to any response bias.
- **Usage patterns**. Respondents can be asked a few questions on the way they use the product. This is not intended to obtain new ideas, but simply to classify the type of user (i.e., heavy vs. occasional, expert vs. novice, etc.) and the occasions and the environment in which usage occurs.
- **Importance of secondary needs**. At the heart of questionnaires aiming to uncover primary needs are questions in which the customer is asked to declare the importance he attributes to each of the $i = 1\ldots m$ secondary needs. "Degree of importance" questions are usually framed so that respondents can provide their rating on a 1–5 or 1–7 scale. Later on, the variables $x_i$ coming from these answers will be analyzed with multivariate statistics techniques, such as factor analysis. This is quite a critical step, since factor analysis should be performed on variables measured on an interval (i.e., cardinal) scale, while 1–5 ratings are inherently ordinal.[14] In order to bring this rating as close as possible to an interval scale, and at least partially overcome this problem, the response should be framed as a *semantic differential scale*. This means that respondents should be provided with a bipolar labeling of the extreme values only (e.g., "1" = not important at all and "5" = extremely important) while intermediate values should not be labeled (as it would be done in a *Likert scale*). In some cases, a 1–4 scale is used, with the objective of forcing customers away from providing a "middle-of-the-way" rating. However, this is a questionable choice, since a "neutral" answer may be genuine and provide a faithful reflection of the way they feel about the item being rated. Moreover, the middle level provides the respondent with an anchor to a neutral response, which can make it less critical to analyze these ratings with statistical tools meant for cardinal data.

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[13]Readers can be referred to Bradburn et al. (2004) or Brace (2008) for an in-depth presentation of this important part of market research.

[14]In other words, in an ordinal scale we know that "2" means more than "1". However, we cannot be sure that the distance between "2" and "1" is the same as between "5" and "4" (which would be true in an interval scale).

- **Perceived quality of existing products**. If possible, respondents can also be provided with a short list of products that are competing in the market, and asked to provide feedback on their perceived quality. This ought to be done using the same list of secondary needs, and asking respondent $j$ to rate the degree with which product $l$ fulfills secondary need $i$ (thus leading to variables $y_{il}$ and individual data points $y_{ijl}$). The usual 1–5 scale can be used to this purpose.
- **Information related to pricing**. Questionnaires can also include a few questions estimating customers' willingness to pay for the product being discussed. More details on this aspect will be provided in the following section.

Based on the dataset that comes out of the survey, it is possible to use multivariate statistics in order to derive primary needs from the importance ratings given to secondary needs (i.e., the variables $x_i$ discussed above). *Factor analysis** is the method that is most commonly employed to this purpose. As mentioned earlier, readers are referred to textbooks on multivariate statistics for a deeper understanding of this method. The following discussion has the simple aim of introducing readers to its specific use in the context of market research for product planning.

By operating on the correlation matrix between variables $x_i$, factor analysis models the original variables as linear combinations of a small set of factors $f_k$ (or latent variables). The coefficients of these linear combinations, which are computed with the objective of explaining as much variance as possible, are called factor loadings $\lambda_{ik}$. Factor loadings tell the analyst which original variables "load" strongly on each factor, thus allowing each factor to be viewed as a grouping of variables that are highly correlated with each other and with the factor. In this specific application, factors represent the latent primary needs that customers tacitly elaborate during the perceptual process, that they would be unable to express, but that can be uncovered thanks to this statistical approach.[15]

In general, factor analysis leads to the definition of 2–4 independent primary needs. Using a higher number of primary needs—though it would allow the explanation of a higher percentage of variance—is generally not advisable, since it would run contrary to the principle that human decision making is carried out using a very limited number of dimensions. Primary needs can be named, based on the constituent secondary needs. For example, the analysis carried out for a durable consumer product such as a city-bike might lead to the three-factor solution shown in Fig. 13.5, in which factor loadings with higher values have been highlighted. By looking at each factor, the analyst may, respectively, interpret the three dimensions as "the bike as a means of transportation" (or "transportation"), "the bike as something you ride" (or "rideability") and "the bike as an ideal and a status symbol" ("ideal"). The first component aggregates all variables that one would consider

[15]For instance, suppose factor analysis shows high loadings of the three secondary needs "I can use my device with one hand", "I can learn how to use my device quickly", "if I make a mistake, my device warns me" on one factor. The analyst may interpret this latent variable as representing a primary need that can be named "ease of use".

**Rotated component matrix [a]**

| | Component | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| SN_confort | -,049 | ,827 | -,054 |
| SN_easy_to_handle | ,201 | ,734 | -,067 |
| SN_no_fatigue_when_pedaling | ,092 | ,494 | ,188 |
| SN_loading_capacity | ,279 | ,311 | -,029 |
| SN_use_outside_city | ,067 | -,109 | ,448 |
| SN_aesthetics | ,011 | ,323 | ,711 |
| SN_safe_when_in_traffic | ,544 | ,376 | -,016 |
| SN_easy_to_lift_and_store | ,696 | ,291 | -,142 |
| SN_does_not_dirty_clothes | ,412 | ,458 | ,149 |
| SN_no_theft | ,674 | ,216 | ,027 |
| SN_reliable_sturdy | ,699 | -,078 | ,107 |
| SN_easy_maintenance | ,665 | -,025 | ,096 |
| SN_accessories | ,010 | ,104 | ,687 |
| SN_brand | -,002 | -,066 | ,807 |

Extraction method: Principal Component Analysis.

Rotation method: Varimax with Kaiser's normalization.

a. Rotation has reached convergence criteria in 5 iterations.

**Fig. 13.5** An example factor analysis, allowing the identification of tacit primary needs

when evaluating the possibility of using a bicycle in alternative to other transportation means. The second component relates to variables that are relevant to its actual use, while the third component takes into account aspects that are somewhat associated to the cultural meaning of the bike.

It may happen that some variables cannot be clearly associated to a component (loading capacity in the example); from a statistical viewpoint, these variables could be pruned from the dataset in order to increase the quality (in terms of variance explained) of the solution. However, the analyst may decide to keep them in, and suggest that the variable pertains to more than one component. In the example, it may in fact make sense to state that "loading capacity" is relevant to both primary needs "transportation" and "rideability". Not being based on explicit judgment, this method for aggregating secondary needs into primary needs can lead to unexpected groupings. For instance, the previous example shows that the need of "a bike that can be used outside the city" is something that customers associate strongly to needs that have to do aesthetic and ideal “values” and not (as it would be expected) to the functional need of having a means of transportation.

Factor loadings do not only allow the uncovering of primary needs and to associate them to the constituent secondary needs. Factor loadings also allow computing synthetic values for latent (or tacit) variables, which represent the importance of each primary need “had the respondent been able to articulate it”. This is important to complete the interpretation of customers’ perceptual process.

Based on the ratings that each respondent $j$ has given to secondary needs (i.e., the values $x_{ij}$) it is possible to compute the rating that the same respondent has implicitly given to each primary need, $x'_{jk}$. Finally, given the ratings assigned by each respondent $j$ to competing products $l$ with respect to the fulfillment of secondary needs $i$, it is also possible to derive the rating that would be given to product $l$ with respect to the primary needs, $y'_{jkl}$. Then, by averaging over $j$, the firm can obtain the implicit rating of that product, concerning its fulfillment of primary needs, $y''_{kl}$.

### 13.4.6 Perceptual Mapping

Thanks to the calculation of latent variables introduced in the previous section, the development team can come up with *perceptual maps**, which are powerful representations of the primary needs arising from the market and of the way with which the industry is fulfilling them. A first perceptual map (Fig. 13.6) can be plotted by representing each respondent according to the values of $x'_{jk}$. This perceptual map shows the distribution of customers with respect to their rating of primary needs and, specifically, if there is any concentration of customers around specific areas of the perceptual map. Should this occur, it would be a clear indication of the existence of customer segments and of potential demand associated to each. Moreover, it is possible to look for correlations or associations between the position on the perceptual map to variables related to demographics or usage patterns. This may provide a much richer description of market segments and of the users that make them up. Figure 13.6 provides the results coming from the previous example of the bicycle, and maps the first two components, checking for gender of respondents. The map shows that it is not possible to identify particularly strong groupings, but one can notice that respondents are absent in the top left area of the map, but not in the bottom right. This suggests that there might be a market for bikes with strong “rideability” and that perform weakly as “means of transportation”, whereas a bike with the opposite features might not find customers. Moreover, observing that position of respondents does not seem to depend on gender, this could be taken as an indication that males and females do not differ with respect to the importance they attribute to primary needs and that—aside from considerations related to sizes and bicycle frame design—it might not make sense to develop separate models.

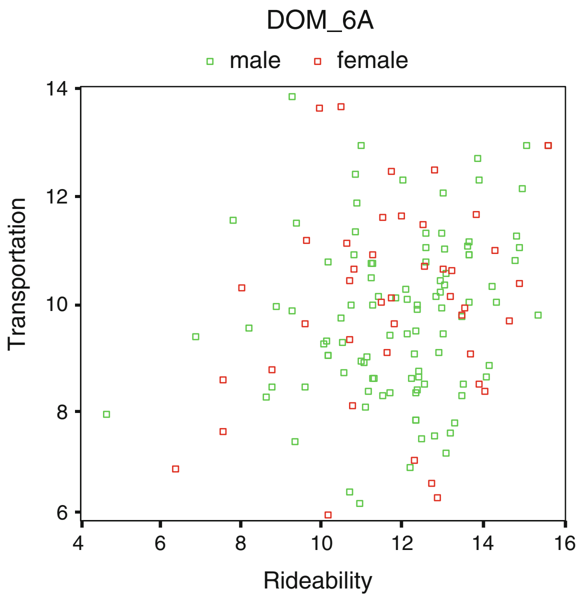


**Fig. 13.6** Perceptual mapping of customers

A second perceptual map can be overlaid to the previous one, by adding a plot of competing products' positioning based on variable $y''_{jk}$ (Fig. 13.7). This map adds information on how products are perceived with respect to fulfillment of primary needs. This map allows spotting any "overcrowding" that may lead to higher degrees of competition, and/or whether there is any portion of the market space that is still underserved. Products can be coded in order to distinguish between brands, and arrows can be added to show trends. For instance, Fig. 13.7 shows that the "mid-market" space where most customers exist is well-covered by existing products, and that perceived quality is progressively increasing. The map also shows a few possibly underserved parts of the market, especially on the right-hand side, characterized by customers having very high requirements with respect to the "driveability" need and medium-high expectations with respect to the "transportation" one.

When looking at this latter perceptual map, some products are distanced from one another by being closer to one or the other axis, but are located at roughly the same distance from the origin. These products differ because producers chose to design them in order to address different primary needs, something that is termed *horizontal differentiation* (a more precise definition will be provided in the following). Conversely, some products are distanced from one another by being located at different distances from the origin, but roughly on the same line that passes by the origin itself. These products differ because of the degree with which they satisfy primary needs, but not because of dissimilar tradeoff choices between these needs. This difference is termed *vertical differentiation*, and allows to distinguish between basic (or entry-level) products and premium (or high-end) ones.

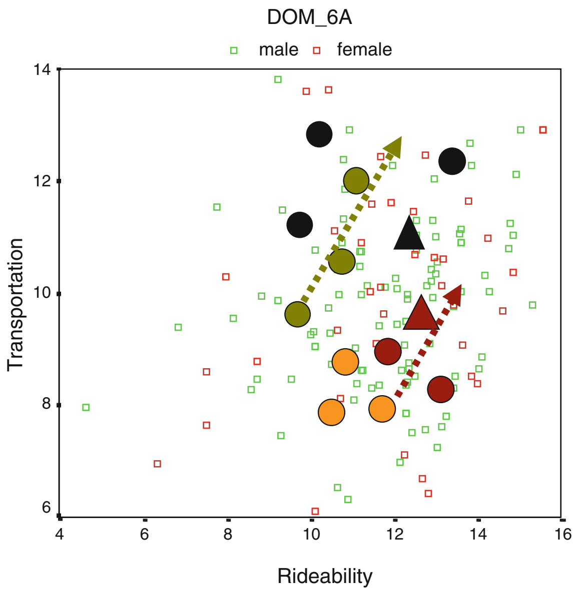


**Fig. 13.7** Perceptual mapping of customers and competing products

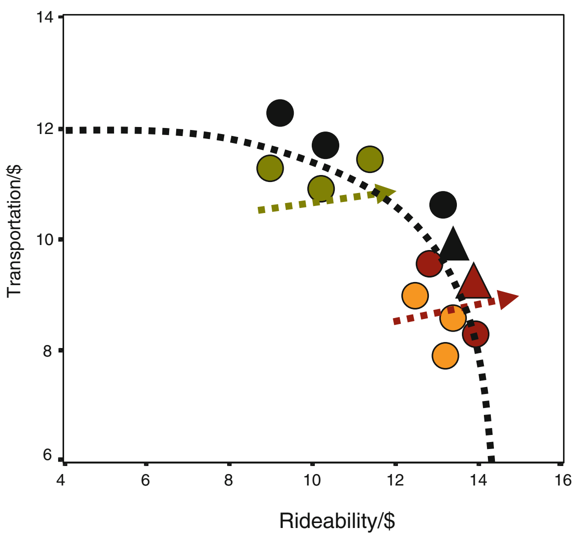


**Fig. 13.8** A value map for positioning products

Of course, basic products can survive in the market because of something that has not yet been captured in the perceptual map, i.e., price. In order to consider this key element as well, the perceptual map can be transformed in a *value map* by dividing the variables $y''_{kl}$ by the price of product $l$, $p_l$, as in Fig. 13.8.

Assuming that the market is made up of rational individuals, one would expect the value map to locate products close to a Pareto-optimal frontier, so that no product dominates any other one. Should this not be the case, the likely reason is that the benefit perceived by customers is not proportional to a simple "needs satisfaction/price ratio", but to a relationship $y''_{kl}/p_l^{\alpha}$, where $\alpha \neq 1$. Therefore, one can try plotting the value map for $y''_{kl}/p_l^{\alpha}$ with varying values of $\alpha$, until the products come close to the frontier and no product appears to be dominant. This information can be very helpful since, should $\alpha > 1$, this implies that customers are willing to pay more than proportionally for high-quality products, and vice versa.

## 13.5 Pricing

Price is a key attribute for any product. When planning a new product, the development team must not only think about the customer needs to be addressed and the associated product features, but also about the price that customers will be willing to pay for it. Pricing decisions are always critical, and a number of techniques can be used to determine it.

Though it is well-known to be a misleading criterion, many firms tend to tackle pricing from an accounting perspective and use a *cost-plus** criterion, estimating costs and adding a desired margin percentage. When doing this, firms mainly look at contribution margins (i.e., the difference between price and variable cost), which must cover product-specific fixed costs, general overheads, and provide profit. Alternatively, given an estimate of demand, a firm may also work on gross margins (i.e., the difference between price and total costs, which include both variable and product-specific fixed costs). Being calculated net of product-specific fixed costs, gross margins must only cover general overheads and provide profit. Though cost-plus pricing theoretically ensures a desired degree of profitability, its use is highly deceptive, since it does not take consumers' willingness to pay into account. In some cases, the calculated price may be too high, leading to weak demand and—ultimately—to the inability to cover fixed costs as forecasted. In other cases it may be too low, and economic value will needlessly be passed down to consumers, who will get a good bargain.

Economists would suggest setting price by equating marginal cost with marginal revenue, but this requires a precise estimation of the demand curve (i.e., how many customers would buy at each price value). Surveys can attempt to extract this kind of information from a sample of consumers by placing questions such as "*what is the maximum amount would you pay for …*?" Unfortunately, answers to this very direct question may not be very reliable. Consumers may either answer lightly by stating a high price (after all, they are not actually taking their credit cards out of their wallets), or "strategically", by declaring a low price (the idea being "*if we all state low values, the firm might make the product more affordable*"). In some

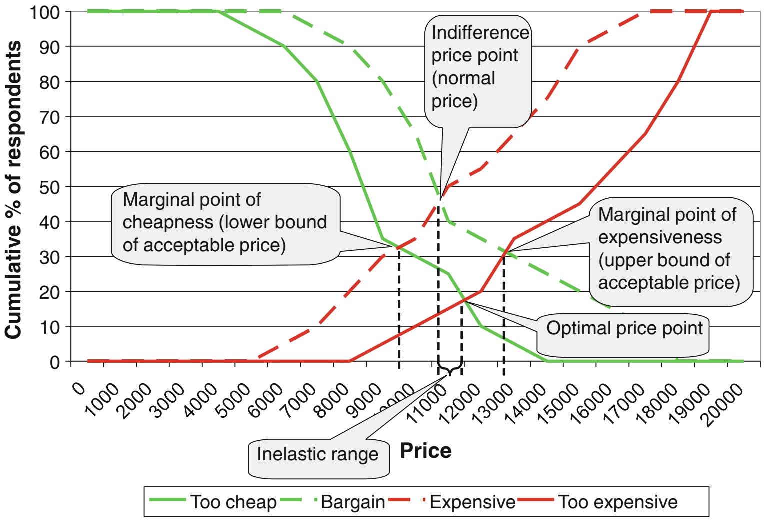


**Fig. 13.9** The price sensitivity meter approach

industries, firms have enough experience to correct the values provided by these answers, but this is not always possible.

A more sophisticated way to extract willingness-to-pay information is the Price-Sensitivity Meter (Van Westendorp 1976). Customers are asked to provide four different pricing values for the product, i.e., a price at which they would not consider buying it (*too expensive*), a price at which they would consider it *expensive* (i.e., not so high as to rule out the purchase, but enough to require some more thoughts); a price at which they would consider it a *bargain* (i.e., they would definitely buy); a price at which they would start doubting of quality (*too cheap*). Based on this data, one can plot the four corresponding cumulated frequencies at the different price levels (Fig. 13.9).

The intersections between the four curves provide ranges for pricing. The intersection between the “too cheap and the “expensive” curve can be considered to be the minimum acceptable price, since by decreasing price further, more customers would be lost because of the perception of “cheapness” than the ones that are gained because of greater affordability. Similarly, the intersection between the “too expensive” and the “bargain” curve is an upper limit for price since, by increasing it further, more customers would be lost than gained. At the intersection between the “bargain” and “expensive” curves there is equilibrium between the number of respondents who consider the product to be cheap and the number who consider it expensive. This point is termed the “indifference price point” (IPP). Another key point is at the intersection between the “too expensive” and “too cheap” curves, which is generally greater than IPP. Proponents of the method claim that the sensitivity of demand between the IPP and this latter point is very low, thus suggesting that price should be set at this very value. For this reason, it is termed optimal price point (OPP).

The above methods are applicable to fairly standardized products, for which it is possible to interview customers and ask them for reference pricing levels. When considering services or configurable products (i.e., products that can be customized with combinations of options and variants), the offering can become so highly customized that the very concept of demand curve tends to disappear. Moreover, when dealing with services such as travel, hospitality, or cloud computing, customers are sold highly perishable production capacity, while variable costs tend to be negligible. In these cases it will be very difficult for firms to make pricing decisions ex-ante. Therefore, producers will continuously experiment with prices, relating them to competition and to the demand they experience in near-real time.

## 13.6 Product Positioning

Product positioning means making a high-level decision on product features and on the market segment to be addressed. Thinking in terms of the perceptual maps that have been described in the previous section, it means describing the new product with respect to the way it satisfies primary needs, eventually in relation to competing products, and defining its target customers.

Apart from very peculiar cases, in which the product category is served by a single product, firms and their competitors will offer a range of differentiated products. The positioning of a new product must therefore take into account its relation to other products being offered by the same firm. As previously mentioned, differentiation can be horizontal or vertical, and a basic understanding of these two concepts is quite relevant to product development choices.

### *13.6.1 Horizontal Differentiation*

Horizontal differentiation is defined by the fact that—by varying product features—utility increases for some consumers and decreases for other ones. For instance, one may think of spiciness of food, or sportiness in the exterior design of a car body, more or less of which may be attractive for some, but not for others.

Following the traditional economic discussion of horizontal differentiation (Hotelling 1929), a firm may find value in pursuing horizontal differentiation because of both demand-side and supply-side reasons. From the side of demand, a customer that finds a product that exactly fits her tastes will derive greater utility than from a product that is positioned at a distance to them. This greater utility implies that she might have a higher reservation price for that product, which leads to a potentially higher margin for the producer. From the side of supply, if firms spread their offering across multiple segments on a horizontal spectrum, this might lead to a thinning of competition, since not all firms will operate in each segment. In turn, less competition increases the likelihood of earning higher margins.

Conversely, horizontal differentiation leads to the partitioning of aggregate demand in many segments. Lower volume in each segment might be unattractive and damaging to profitability, by forcing to give up on economies of scale that could be pursued with a single "central" offering. This explains why firms usually try to achieve economies of scope, i.e., the possibility of reducing cost by widening the range of products being made, through shared platforms and flexible manufacturing systems.

From a practical perspective, product positioning along a horizontal dimension will require to estimate the size of each market segment, of their customers' willingness to pay, and of the sensitivity of demand with respect to offerings that do not exactly match needs. The higher each of these factors, the more likely it will be that a product oriented to the segment will be economically viable, even if this entails a given amount of specific investment.

### *13.6.2 Vertical Differentiation*

In the case of vertical differentiation, the variation of product features will lead to a corresponding variation of customer utility that will have the same sign for all customers. For instance, a car with greater mileage will always be better than a car with less mileage, though some customers might be more sensitive to this variation than other ones. Product features leading to vertical differentiation will generate a segmentation that runs from products that are perceived to be of lower attractiveness (and will have to be priced at a lower level) to products that are highly desirable (and will be able to command higher prices).

As in the previous case, the economic reasons behind vertical differentiation are connected to both demand side and supply side aspects. Looking at demand, vertical differentiation allows price discrimination, so that customers who highly appreciate quality and are prepared to pay for it are effectively charged a high price, while customers with lower willingness to pay are charged correspondingly, and receive a lower-value product. By not practicing vertical differentiation, a firm would have to position a single product at an intermediate level of quality and price. The firm would therefore lose part of demand, made up of customers with a lower reservation price. Moreover, it would also lose part of the potential profits on customers whose reservation price is higher than the practiced one. As in the case of horizontal differentiation, by spreading offerings along vertically differentiated segments, competitive pressure in each segment might be reduced, which allows firms to retain the margins that come from price discrimination.

Vertical differentiation too leads to a smaller volume sold to each segment and, therefore, to giving up potential economies of scale. A further and particularly important risk connected to vertical differentiation is *cannibalization*. This occurs

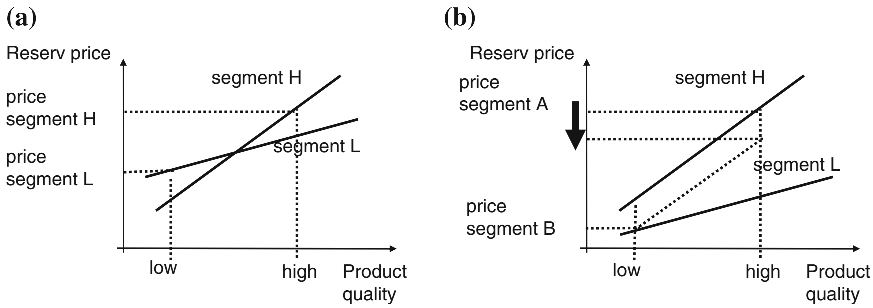


**Fig. 13.10** The economics of cannibalization due to vertical differentiation

when customers who would be willing to buy a high-level product opt for a low-level product, which is therefore said to cannibalize the former.

Cannibalization can be explained by referring to the two cases in Fig. 13.10. The graphs shows the way reservation prices change as a function of quality for two customer segments, labeled H (for "high") and L (for "low"). Based on these curves, a firm can identify a "high" price and a "high" quality for the corresponding segment, and a "low" price and quality for the other.

In the graph on the left-hand side, the utility curves of the two segments cross. In this case, cannibalization does not occur, and customers in each segment will buy the product that is aimed at them. Specifically, customers in the "high" segment find a "high quality" product at a price equal to their reservation price for that quality, and will therefore buy it. These same customers will not buy the "low quality" product, since their reservation price for that product is less than the practiced price. If we now look at the "low" segment, these customers will accept buying the "low quality" product at the corresponding reservation price. They will not buy the "high quality" product, since its price is greater than their reservation price for it.

In the graph on the right-hand panel, utility curves do not cross, leading to cannibalization. In this case, the "low" segment keeps on buying the "low quality" product. However, customers in the "high" segment will compare the two products and find out that—while their reservation price for the "high-quality" product is the same as the practiced price—their reservation price for the low-quality product is higher than the practiced price. They will therefore prefer the latter product, since it gives them come customer surplus, while the former one would leave them with none.[16] From the perspective of the producer, this is likely to be damaging, since margins coming from the high-end product are usually higher than the ones accruing from the low-end one.

Due to the risk of cannibalization, firms with a vertically differentiated product range must pay attention to the origin of its buyers and monitor their behavior.

[16]As an example of cannibalization, think of a luxury car manufacturer that starts selling compact cars alongside to traditional sedans, and discovers that customers of the latter are moving to the cheaper and model.

**Table 13.1** Cannibalization can lead to profit-damaging vertical differentiation

| | Before introduction of luxury compact | | | | After introduction of luxury compact | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Business | Premium | Top | Total | Luxury compact | Business | Premium | Top | Total | Δ |
| Average unit price (Euros) | 30,000 | 50,000 | 70,000 | | 25,000 | 30,000 | 50,000 | 70,000 | | |
| Contribution margin | 25 % | 30 % | 35 % | | 15 % | 25 % | 30 % | 35 % | | |
| Unit contribution margin (Euros) | 7500 | 15,000 | 24,500 | | 3750 | 7500 | 15,000 | 24,500 | | |
| Volume sales (thousand units) | 750 | 400 | 200 | 1350 | 600 | 500 | 350 | 190 | 1640 | 21.48 % |
| | 56 % | 30 % | 15 % | 100 % | 37 % | 30 % | 21 % | 12 % | 100 % | |
| Sales (million Euros) | 22,500 | 20,000 | 14,000 | 56,500 | 15,000 | 15,000 | 17,500 | 13,300 | 60,800 | 7.61 % |
| | 40 % | 35 % | 25 % | 100 % | 25 % | 25 % | 29 % | 22 % | 100 % | |
| Margins (million Euros) | 5625 | 6000 | 4900 | 16,525 | 2250 | 3750 | 5250 | 4655 | 15,905 | −3.75 % |
| | 34 % | 36 % | 30 % | 100 % | 14 % | 24 % | 33 % | 29 % | 100 % | |

While clients who *expand* the customer base are of course welcome, some clients may be actually *downshifting* from higher-quality products, and therefore reduce the overall profitability of the firm. In the example shown in Table 13.1, luxury carmaker ABC tries adding a "luxury compact" car to its product range, which cannibalizes sales from the adjoining "business" segment and—by reducing brand equity—leads to a small decrease in the sales to higher-level segments. Overall, volume and dollar sales increase and the new "luxury compact" model seems to be a "rising star" in the carmaker's product range. However, a closer analysis shows that overall margins decrease, and that the main responsible is this apparently beneficial new car model.

In order to avert cannibalization, a firm can use a number of strategies, among which (Moorthy and Png 2002; Krishnan and Zhu 2006):

- Decreasing the price of the high-level product, in order to leave the customers in the "high" segment with the same surplus they would have by purchasing the low-level product. This strategy is easy to enact, but has the obvious disadvantage of reducing profits.
- Developing the low-level product so that the utility curves intersect. This can be done by purposely degrading the quality of the low-level product, until the quality and price fall to the left of the intersection between the utility curves[17] (e.g., ABC could strip the "luxury compact" car of features and accessories that are usually desired by buyers of that brand). This strategy has the drawback of affecting the market for the "low-level" product, and bears the risk of reducing brand equity for the whole product range (e.g., "*ABC is not making cars like they used to!*").
- Introducing horizontally differentiating features in the low-level product, in order to make it more appealing to the "low" segment and less to the "high" segment (e.g., ABC could aim the "luxury compact" car toward a younger audience, give it a more aggressive styling and a slightly less comfortable ride). In this case too, the firm must be careful not to spoil the attractiveness of the brand.
- Enacting marketing actions aimed at reducing the "high" segment's perception of utility for the low-level product, thus making the utility curve for the "high" segment steeper. This strategy is similar to the previous two ones, but it is played on customers' perceptions instead of objective features. For instance, TV commercials for the "luxury compact" cars could feature young people in their 20s, thus conveying the image that it is not the right model for older and more affluent customers. The risk of damaging the perception of the brand is of course always present.
- Giving up the idea of vertical differentiation and pursuing a "niche" product strategy, producing the "high level" or the "low level" product only. A similar

[17] In 1849, the French economist Jules Dupuit noticed that railways companies were purposely making third-class carriages uncomfortable not to reduce cost, but in order to "scare away" customers who had enough money to buy second- and first-class tickets.

strategy could also consist in selling the two products under two different brands. However, introducing a new brand to the market is not a small endeavor and requires significant investment.
- Using time as a further discriminating variable and launching the "high-level" product sufficiently earlier than the "low-level" one. Of course, this strategy has a negative impact on the sales of the latter product.

## 13.7 Demand Forecasting

One of the main elements to be considered when making product positioning choices is potential demand. In general, the forecasting of demand for product j can be done using the following simple model

$$D_j = DS_j \mathrm{AW}_j \mathrm{AV}_j \tag{13.2}$$

where

- $D_j$ is demand for product $j$,
- $D$ is a forecast of overall demand in the market segment,
- $S_j$ is the market share that product $j$ could potentially achieve, based on its features, and is therefore directly connected to design decisions,
- $\mathrm{AW}_j$ (awareness) is the fraction of target customers who can be expected to know of the product's existence, which is related to marketing actions that the firm will undertake to this purpose,
- $\mathrm{AV}_j$ (availability) is the fraction of target customers who will be able to purchase the product, based on the distribution strategy followed by the firm.

When following this model, a well-focused definition of the market segment and of competing products is crucial. In fact, it would be absurd to define a broad market with hundreds of quite different competing products, and to estimate a minuscule market share. On the other side, it could be dangerous to define a very narrow segment with very few offerings (at the limit, only one) but neglecting the potential competition coming from contiguous segments. The following sections will outline a few elements that can be used in estimating the first two parameters, which are more directly linked to choices made in the product development process.

### 13.7.1 Demand in Stationary Markets

When dealing with products that are in the "mature" phase of s-curves, demand can be expected to be constant. Alternatively, demand may follow some trend, or it might be correlated to other phenomena that drive sales. In all these cases, demand

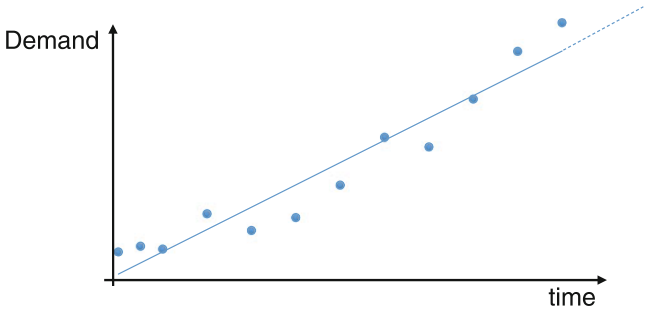


**Fig. 13.11** Example of a simple time-series analysis leading to a forecast by extrapolation

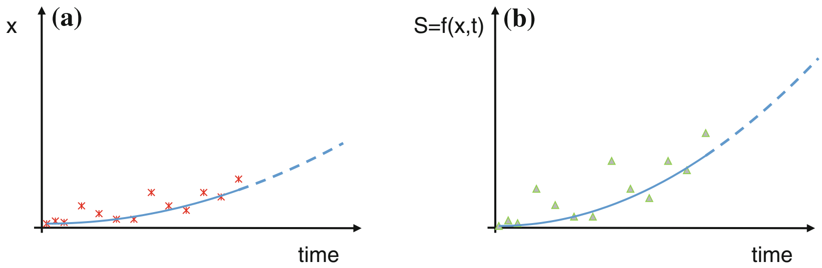


**Fig. 13.12** Example of a forecast based on a trend and a correlation with an independent variable

can be considered to be "stationary" in the sense that is not affected by the dynamics of diffusion effects. In these cases, demand forecasting is performed using standard time-series analysis methods coming from statistics and econometrics. We will not discuss this topic, and refer readers to specialized textbooks (e.g., Box et al. 2008; Jain and Malehorn 2005). However, we will at least mention the difference between autonomous and dependent models.

In the former case, the firm observes demand over a stretch of time and tries to extrapolate it into the future by referring to the past values of the demand time series only. This may occur when demand is either constant or follows a constant trend (Fig. 13.11).

Should demand exhibit a more complex pattern, this might indicate that an underlying and independent phenomenon is driving sales. A forecast can therefore be performed by studying the correlation with this underlying phenomenon, and then using independent forecasts of the independent variables. For instance, sales of child seats for cars are dependent on birthrate and car ownership. A company having to make sales forecasts for this product can obviously derive them from demographic forecasts by national statistics offices (concerning the former factor), and from forecasts by industry bodies for the latter one (Fig. 13.12).

As a final note, it should be considered that measuring demand is not a trivial task. Sales data at market level may be difficult to access, and sources usually include specialist market research firms, or trade associations. Moreover, one can observe sales, but not demand. In most instances the two coincide, but this is not necessarily so. If supply is restricted, or if availability and awareness are limited and do not allow to cover the whole market, potential demand could be quite larger than sales.

## 13.7.2 Demand Subject to Diffusion Phenomena

### 13.7.2.1 The Bass Model of Diffusion

When dealing with innovations that are in the incubation or diffusion stage, demand must be studied by explicitly considering the diffusion phenomenon.

Early scholars who studied diffusion phenomena focused on two alternative diffusion paths, one following a negative exponential law (Fourt and Woodlock 1960) and one following a logistic (s-shaped) curve (Mansfield 1961). In 1969, Frank Bass merged these two approaches into a model that bears his name and is the most widely used representation for this kind of phenomenon.

Bass' model is based on a set of apparently quite restrictive hypothesis, which are listed in the following. Variants of the Bass model, which will be discussed later on, allow the relaxation of some hypothesis, justifying a broad application of the model.

- Demand is modeled at the level of the overall market. Using the model at the level of sales for an individual firm is justifiable in the case of monopolies;
- The product being studied is durable, without any substitution or additional sales. Should this not be true, the model can validly represent diffusion sales (i.e., the first sale occurring to customers who were not previously adopters of the good);
- Diffusion of the good being studied is completely independent of demand for other goods. This hypothesis is very strong, since it means that the good is so innovative that it is neither a substitute nor a complement to any other good being sold on the market;
- Marketing actions by the firm (i.e., price, promotion, and advertising) are constant throughout the diffusion phenomenon. This is another very strong hypothesis, since firms normally vary marketing effort throughout the product lifecycle;
- Customers' adoption process is binary, in the sense that customers' purchases are limited to one item. This can be easily accepted for adoption sales in consumer markets, but rules out the possibility of using the model for corporate sales, especially if the size of customer companies is heterogeneous.

Based on these hypotheses, the Bass model can be defined by the following difference equation

$$n_t = N_{t+1} - N_t = p(M - N_t) + \frac{q}{M}(M - N_t)N_t \tag{13.3}$$

where

$n_t$ is sales at time $t$,
$N_t$ are cumulated sales at time $t$,
$M$ is the market size, and represents the saturation level for the diffusion phenomenon,
$p$ is the "innovative adoption parameter",
$q$ is the "imitative adoption parameter".

Bass' model posits that, at any given point in time, diffusion occurs because a subset of the non-adopters, $M - N_t$, switches to the status of adopters. This switch can occur because of the sum of two phenomena. The former is called *innovative adoption* and depends on non-adopters' willingness to adopt, combined with communication acts that are broadcast by producers to induce them into adoption. This phenomenon is modeled by hypothesizing that, at any time unit, a fixed proportion p of non-adopters will switch to the status of adopters.

The latter is termed "imitative adoption", and depends on effects that are internal to the market, including word of mouth (i.e., the influence that adopters cast on non-adopters) and network externalities. The phenomenon is modeled by stating that, at any time unit, the number of imitative adopters will be a fixed proportion q of non-adopters, weighted by the fraction of adopters (who are the ones who generate the imitative effect).

The Bass model can also be written as a differential equation

$$n(t) = \frac{\mathrm{d}N(t)}{\mathrm{d}t} = p[M - N(t)] + q\frac{M}{N(t)}[M - N(t)] \tag{13.4}$$

which, integrated, leads to a closed-form solution for the evolution of sales

$$n(t) = M\frac{p(p+q)^2 \mathrm{e}^{-(p+q)t}}{\left(p + q\mathrm{e}^{-(p+q)t}\right)^2} \tag{13.5}$$

while the evolution of the diffusion process (i.e., cumulated sales) is given by

$$N(t) = M\frac{1 - \mathrm{e}^{-(p+q)t}}{1 + \frac{p}{q}\mathrm{e}^{-(p+q)t}} \tag{13.6}$$

The time at which the sales peak occurs is located at the extremum where $\frac{\mathrm{d}n(t)}{\mathrm{d}t} = 0$, and its value is given by:

$$t^* = \frac{1}{p+q}\log\left(\frac{p}{q}\right) \tag{13.7}$$

Therefore, at this extremum, sales amount to:

$$n(t^*) = \frac{M(p+q)^2}{4q} \tag{13.8}$$

Finally, the penetration level that is reached at the sales peak is given by:

$$N(t^*) = M\left(\frac{1}{2} - \frac{p}{2q}\right) \sim \frac{M}{2} \tag{13.9}$$

since, in most cases, $p \ll q$. Equation (13.9) shows that, whatever the values of q and p, the inflection point will be reached when approaching half of the maximum penetration level. This can be seen as a useful "rule of thumb" and allows foreseeing the position of the sales peak if $M$ is known or, conversely, to estimate $M$ when the inflection point has been reached.

When attempting to estimate the parameters in the Bass model, one must refer to the finite difference equation (13.3) and transform it in the autoregressive form (13.10)

$$N_{t+1} = pM + N_t(1 - p + q) - \frac{q}{M}N_t^2 \tag{13.10}$$

Based on (13.10), parameters can be estimated, but the strong multicollinearity between variables $N_t$ and $N_t^2$, significantly weakens the statistical reliability of the results. Therefore, one might get good estimates only when a sufficiently long time series is available, though this means that the diffusion process is over and there probably is no more need for a forecast. Because of this contradiction, forecasts based on the Bass model are usually run by referring to analogies and using values of p and q that occurred for similar products in similar markets (Mahajan et al. 2000; Satoh 2001).

#### 13.7.2.2 Managerial Implications of the Bass Diffusion Process

As shown in Fig. 13.13, the shapes of diffusion curves resulting from the Bass model depend on values $p$ and $q$. In case of predominantly innovative diffusion (i.e., if $q$ is negligible) as in the left-hand panel of the figure, the curve will get close to a negative exponential. This is typical of fast-moving and low-ticket consumable products, for which adoption choices are relatively frictionless (e.g., a new type of toothpaste is likely to be adopted for a first trial quite quickly by the market, essentially because of advertising).

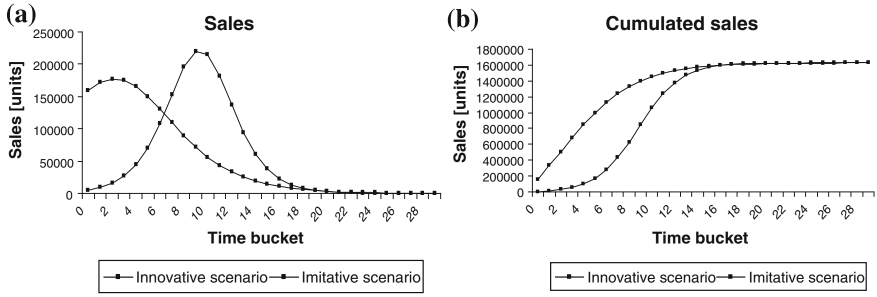


**Fig. 13.13** The weight of innovative and imitative adoption determines the shape of diffusion curves in the Bass model

Conversely, in case of mainly imitative diffusion (i.e., if $p$ is very small with respect to $q$), the curve will resemble a logistic curve. This is typical of durable products whose adoption requires a significant outlay. In these cases, customers will hesitate and wait for confirmations of the product's validity coming from their peers, before actually "taking the plunge" and purchasing it.

The shape of the adoption curve depends on the nature of the product, but can also be influenced by the firm. Innovative adoption can be stimulated by advertising spending, while the imitative phenomenon can be influenced by actions that are often described as *viral marketing**. Examples range from referral coupons (e.g., "*bring a friend and gain something*") to introducing features that stimulate network externalities (e.g., "*shoot a movie and share it with your friends*").

Whether a firm should prefer a rapid diffusion, as in the case of mainly innovative diffusion, or a slower one, as in the case of imitative, depends on the nature of the industry, of the goods being sold and on the type of production capacity. This latter factor is quite important, since innovative diffusion requires maximum production capacity to be available at a very early stage of the diffusion process, whereas imitative diffusion allows a progressive build-up of capacity. Moreover, with imitative diffusion, the time lag between the start of the process and the sales peak allows the firm to build up inventory and/or to install a somewhat lower capacity and then increase output by relying on learning economies.

Therefore, firms will strive to achieve innovative diffusion if there is some kind of early-mover advantage to be exploited, provided the investment required to acquire a customer is not excessive and provided production capacity is not an issue. This can be the case of goods that can be produced with non-specific facilities, such as books to be printed, or printed circuit boards to be assembled. It can also be the case of goods that lead to repeat business (e.g., services or consumable products), since in this latter case the required capacity depends on the repeat consumption rate and the number of adopters being reached, rather than on the maximum adoption rate. When capacity is a constraint and if the firm aims for a quick innovative-diffusion type of process, it is customary to stagger the launch date of the new product across geographical markets, in order to smooth out the sales peak.

#### 13.7.2.3 Some Variants of the Bass Model

As mentioned above, the Bass diffusion model is based on restrictive assumptions, and a number of variants have been developed over the years, each one aimed at relaxing one or the other of these assumptions. We will briefly discuss some of them in the following.

- **Variable market potential and price**. The market potential of an innovation may vary in time because price is not held constant. For instance, in a competitive market, price will tend to decline, due to the decrease in costs that is determined by learning effects. At the same time, the economic environment may change, leading to a greater or lesser willingness to pay. Horsky (1990) attempted to model this case by modifying the Bass differential equation (13.2) as follows:

$$n(t) = \left[\frac{M}{1 + \mathrm{e}^{-\frac{k+w(t)-\mathrm{pr}(t)}{\mathrm{var}(w(t))}}} - N(t)\right][p + qN(t)] \tag{13.11}$$

  where

  $M$ is the maximum potential for diffusion,
  $\mathrm{pr}(t)$ is the time-varying price of the good,
  $K$ is the utility of the good,
  $w(t)$ is the available income within the population, expressed as a stochastic variable with expected value $E[w(t)]$ and variance $V[w(t)]$.

- **Variable price and marketing actions**. In 1994, Bass proposed what he called a "generalized" version of his original model. As shown in (13.12), instantaneous sales depend on the relative rate of change of price $\mathrm{pr}(t)$ and advertising effort $A(t)$, as expressed by (13.13):

$$n(t) = [M - N(t)][p + qN(t)]x(t) \tag{13.12}$$

$$x(t) = 1 + \beta_p \frac{\mathrm{dpr}(t)/\mathrm{d}t}{\mathrm{pr}(t)} + \beta_A \frac{\mathrm{d}A(t)/\mathrm{d}t}{A(t)} \tag{13.13}$$

  Now, if $\mathrm{pr}(t)$ and $A(t)$ do change, but their relative rate of change is constant over time, $x(t)$ will effectively remain constant. In this case, the generalized Bass model falls back into the original Bass model, only with modified values for $p$ and $q$. The generalized Bass model is seldom used as such, but provides an interesting perspective that justifies the use of the *standard* Bass model beyond some of its restrictive assumptions, simply if the rate of change of $\mathrm{pr}(t)$ and $A(t)$ are constant. Concerning the former, price is generally tied to variable cost and, as it will be seen in Chap. 14, variable cost drops in time following laws that are quite close to the exponential (which implies a constant rate of change). Concerning advertising expenditure, we know that the evolution of sales at the beginning of the diffusion s-curve is close to an exponential. Now, if the firm defines its advertising budget as a constant percentage of sales, advertising expenditure will follow the same evolution too.

- **Complementarity or substitution effects**. The hypothesis that the good does not exhibit any kind of economic relationship with other goods is of course very strong. A substitution effect due to competition with other goods is generally present. Similarly, the complementarity with other goods can often be a strategic element that has to be considered in order to support the diffusion process. The Bass model can be modified in order to represent the joint diffusion of related goods through Eqs. (13.14) and (13.15):

$$\begin{aligned} n_1(t) = p_1[M_1 - N_1(t)] + q_1 \frac{M_1}{N_1(t)}[M_1 - N_1(t)] \\ + r_{21} \frac{M_2}{N_2(t)}[M_1 - N_1(t)] \end{aligned} \tag{13.14}$$

$$\begin{aligned} n_2(t) = p_2[M_2 - N_2(t)] + q_2 \frac{M_2}{N_2(t)}[M_2 - N_2(t)] \\ + r_{12} \frac{M_1}{N_1(t)}[M_2 - N_2(t)] \end{aligned} \tag{13.15}$$

This model adds a cross-goods diffusion effect, in which sales of good 1 also depends, through an additive term, on the penetration reached by good 2. The phenomenon is governed by parameters $r_{21}$ and $r_{12}$, which can be either positive or negative, depending on the type of relation between the goods. The model is quite straightforward to understand, though its use can be hindered by the difficulty of finding a proper estimate for the two parameters.

- **Two-sided markets**. These markets are based on a platform allowing the interaction between different groups (customers, individuals or companies). Each group involved receives benefit from the use of the platform, and the demand of each group dependents on the demand of the other. Notable examples of two-sided markets (platform, side 1, side 2) are credit cards (card network, card holders, stores), mobile phones (operating systems, users that download apps, app developers), and videogames (consoles, players, game publishers). In these cases, the diffusion of an innovation on one side determines diffusion on the other, and vice versa. For example, in the diffusion of an operating system, the higher the number of users adopting the operating system, the higher the number of application developers who will choose to write software applications. At the same time, the higher the number of available applications, the higher the adoption rate from the perspective of users. Chun and Hahn (2008) have shown that, being—being $\alpha$ the coefficient of influence with which one side of the market influences the demand on the other side—the differential equation for the Bass model can be written *for both sides* as:

$$
\begin{aligned}
n(t) &= \left[p + qN(t)\frac{\alpha e^{N(t)}}{\alpha e^{N(t-1)}}\right][1 - N(t)] \\
&= \left[p + qN(t)e^{[N(t)-N(t-1)]}\right][1 - N(t)]
\end{aligned}
\tag{13.16}
$$

- **Replacement sales**. In the case of consumables or durables with finite durability, sales are not limited to adoption sales since customers will purchase the item more than once. Equation (13.17) shows that overall sales at time t will be given by the sum of adoption, replacement and additional sales of the *i*th item (i.e., the sales to customers who buy their 2nd, 3rd, 4th, etc. similar product).

$$
s_t = n_t + r_t + \sum_{i=1}^{l} v_{i,t} \tag{13.17}
$$

Looking at (13.17), adoption sales can easily be modeled as previously discussed. Substitution sales can instead be modeled by reliability functions $R_t$, which express the probability that a good is still usable $t$ time units after its initial purchase.

$$
r_t = \sum_{t'=1}^{t} (R_{t-t'} - R_{t+1-t'})s_{t'} \tag{13.18}
$$

where the term in brackets represents the probability of a good purchased in $t'$ to fail between $t$ and $t + 1$, thus leading to a replacement sale. Overall replacement sales at time $t$ will then be given by the sum of the replacement sales deriving from the sales made at all previous purchasing instants. Alternatively, a simplified relationship for substitution sales is given by

$$
r_t = \frac{N_t}{T} \tag{13.19}
$$

where $N_t$ is the stock of adopters at time $t$ and $T$ is the average time between substitutions. This relationship is generally valid at steady state, but can be misleading during the early phases of diffusion, when not enough time has passed for products to break down and need replacement.

The modeling of additional sales is quite involved and, for the sake of brevity, we will not discuss them here (more can be found in Ratchford et al. 2000). The basic approach is to estimate the probability with which customers already owning i’ similar items may decide to purchase their $i' + 1$th, and then multiply it by the number of such customers.

Recent advances in the field of innovation diffusion models have been based on an explicit representation of customer choice over time. Decker and Gnibba-Yukawa (2010) have proposed a model in which a product evolves along the s-curve, with this evolution being represented by a quality-adjusted price at time $t$, $P_t$. At each instant, potential adopters evaluate the expected utility $E[U_t]$ they would derive by adopting at time $t$, where $U_t$ is a function of $P_t$ and $N_{t-1}$ (which includes word-of-mouth and network externality effects). Moreover, they evaluate the expected utility they would derive by postponing the adoption until $t + 1$ and discount it by an "impatience factor" $\delta < 1$. If $E[U_t] > \delta E[U_{t+1}]$ adoption will occur. Conversely, if $E[U_t] < \delta E[U_{t+1}]$, the adoption choice will be shifted to the next time unit. The authors show that the difference equation that captures this behavior is given by Eq. (13.20)

$$n_t = \frac{M - N_{t-1}}{1 + e^{-[\beta_0 + \beta_1 \ln(N_{t-1}) + \beta_2 (P_t - \delta P_{t+1})]}} \tag{13.20}$$

where

- $\beta_0$ is a constant that represents innovative diffusion (in fact, should $\beta_1 = 0$ and $\beta_2 = 0$, Eq. (13.20) would fall back to the description of a purely innovative diffusion phenomenon);
- $\beta_1 > 0$ and represents imitative diffusion including network externality effects (the greater $\beta_1$ and the greater is the stock of adopters, the higher the sales);
- $\beta_2 < 0$ represents the "wait and see" attitude followed by potential adopters. If $P_{t+1} \ll P_t$ this will reduce the number of new adopters at time $t$, since many will postpone adoption. Conversely, if $P_{t+1} > P_t/\delta$, potential customers will adopt at time $t$ because their impatience is greater than the benefits coming from the expected price reduction.

The previous models show that innovation diffusion phenomena have traditionally been studied analytically, using differential equations. This approach does not allow the modeling of complex decision-making behaviors and the heterogeneity that is inherent to the population. An alternative approach has recently emerged, with the use of agent-based simulation (Kiesling et al. 2012). In agent-based simulation, the diffusion of an innovation is modeled on the basis of a microlevel representation of a population of individual agents, with an explicit coding of their individual decision-making process leading to adoption, of their reciprocal interactions based on underlying social networks, and of their heterogeneity. Of course, as is the case for all powerful computational tools, the ability to represent very minute facets of the system's behavior leads to the challenge of identifying relevant parameters in a reliable way, which might not be an easy task.

As a final comment, demand forecasting for B2B products can be roughly forecasted by the previously discussed models. However, adoption of a good by a business generally follows a complex process such as the one represented in Fig. 13.14, in which demand is essentially driven by the effort spent on direct sales.

In these cases, the Bass model is hardly applicable. Word of mouth is usually much less relevant than for consumer products, while marketing effort is aimed at one-to-one action (Monat 2011). This is markedly different from the mechanism underlying the Bass model, in which marketing is broadcast to the residual

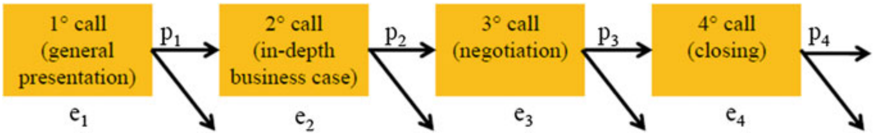


**Fig. 13.14** Representation of the B2B purchasing process

population of non-adopters at time $t$, $M - N_t$. For B2B products, one can try forecasting diffusion as a function of sales effort, by modeling the sales cycle as in the previous Fig. 13.14, and identifying relevant parameters (i.e., conversion rates from one step to the other, and costs of each step).

### 13.7.3 Market Share

A second parameter to be determined when forecasting sales is the potential market share of the product. A straightforward way to estimate this parameter is based on the so-called Kotler's theorem. This theorem relates market share of each product i, $s_i$, to a measure of "attractiveness" $A_i$ that characterizes each product. The theorem is based on the following four axioms.

**Axiom 1.** $A_i \geq 0 \ \forall i$, $\Sigma_i A_i > 0$ (attractiveness of products is always non-negative, and at least one product has non-zero attractiveness).

**Axiom 2.** $A_i = 0 \rightarrow s_i = 0$ (a product with zero attractiveness will have no market share).

**Axiom 3.** $A_i = A_{i'} \rightarrow s_i = s_{i'}$ (two products with equal attractiveness will have the same market share).

**Axiom 4.** If $A_i := A_i + \Delta$, the decrease in $s_{i'}$ will be a function of $\Delta$ and not of $i$ (market share of product $i'$ changes as a function of the overall attractiveness of products in the market).

Axioms 1 and 2 provide a basic definition for attractiveness and its influence on market share. Axiom 3 states that market share is determined by attractiveness alone. Axiom 4 is slightly more problematic, since it states that changes to the products being offered on the market impact the market share of a product only through their combined attractiveness. Now, it might be argued that, for certain brands, the competitive impact of product change might be higher than for other ones. However, this consideration is quite inconsequential, since we have not defined what attractiveness is, and this concept may very well incorporate this "sensitivity to the brand" aspect.

Based on these four axioms, it follows that market share of product $i'$ will be given by the following relation:

**Table 13.2** Using Kotler's theorem to estimate the impact of competitive moves

| Company | Case 1 (no reaction by $Z$) | | | Case 2 ($Z$ fights back) | | |
|---|---|---|---|---|---|---|
| | Before the new competitor enters | After the entrance of $Z$ | Actual market share | Before the new competitor enters | After the entrance of $Z$ | Actual market share |
| $X$ | 0.45 | 0.45 | 0.33 | 0.45 | 0.45 | 0.31 |
| $Y$ | 0.3 | 0.3 | 0.22 | 0.3 | 0.3 | 0.21 |
| $Z$ | 0.25 | 0.25 | 0.19 | 0.25 | 0.36 | 0.25 |
| New | – | 0.35 | 0.26 | – | 0.35 | 0.24 |
| Total | 1 | 1.35 | 1 | 1 | 1.46 | 1 |

$$S_{i'} = \frac{A_{i'}}{\sum_i A_i} \tag{13.21}$$

The consequences of Kotler's theorem are quite interesting. First of all, given a set of n products with similar attractiveness, the market is going to be divided into n equal shares, which is not surprising at all. However, a product whose attractiveness is much higher than that of its competitors is not going to achieve 100 % market share, while a product with low attractiveness will have a small, but non-zero market share. This outcome seems to contradict the hypothesis of a rational consumer, but is quite consistent with consumer behavior and with the heterogeneity of markets. Finally, relation (13.18) ensures that, if new competing products are launched, or if products' attractiveness changes, market shares will self-adjust so that their sum always yields 100 %.

As mentioned, Kotler's theorem does not tell us what attractiveness is and how it may be calculated. However, this vagueness can be considered to be the beauty itself of the theorem. Given current market shares from sales data, an analyst can quickly derive the implicit attractiveness of competing products, since $A_j = \alpha s_j$ where $\alpha$ is any real number. For simplicity, one can consider $\alpha = 1$ and posit that, given current market share, $A_j = s_j$. It becomes straightforward to make rough estimates of market shares in a changing competitive scenario in which new products are defined in terms of their relation to the attractiveness of the existing ones. Table 13.2 provides a simple example of a market with three competitors, $X$, $Y$, and $Z$. Based on this data, it is fairly easy to answer questions such as "*what would happen if a new entrant launches a product whose attractiveness is intermediate between the one of product X and product Y*?" and "*in addition, what would happen if competitor Z fights back with a new product whose attractiveness is 20 % higher than the one of product Y?*".

In addition to these rough estimates based on implicit attractiveness indexes, it is also possible to investigate on the relationships between technical features of the products and attractiveness (Cooper and Nakanishi 1988). These relationships are generally non-linear, and are expressed through models that can be identified using data on past sales. The most well-known models are the following:

- **MNL, or Multinomial Logit**. The attractiveness $x_{ki}$ of product $i$ is considered to be a function of a set of technical features $k$, of a parameter $\alpha_i$ that represents the influence of brand $i$ and of parameters $\beta_i$ whose estimation can be given by data on past sales.

$$A_i = \mathrm{e}^{\alpha_i + \sum_k \beta_k x_{ki} + \varepsilon_i} \tag{13.22}$$

- **MCI, or Multinomial Competitive Interaction**. This model is similar to MNL, but the function expressing attractiveness is multiplicative, similarly to a Cobb–Douglas function:

$$A_i = \mathrm{e}^{\alpha_i} \prod_k x_{ki}^{\beta_k} \varepsilon_i \tag{13.23}$$

When working on market share models, price is of course an important element to be considered. In general, it is possible to include it as one of the parameters $X_{ki}$. Alternatively, price could be neglected if the market is highly competitive, or if the study is focused on a narrow segment of the market, since in these cases prices will broadly be aligned for all competing products.

Following the procedure in Fig. 13.15, the existing scenario allows the estimation of relevant parameters, which can then be used to make a forecast of future scenarios that include the launch of new products and/or modifications to the current ones.

The main difference between the MNL and MCI models can be understood by computing the elasticity of the resulting market share with respect to the values of parameters $X_{ki}$. For simplicity, let us suppose that customers prefer high values of $X_{ki}$ over low values.

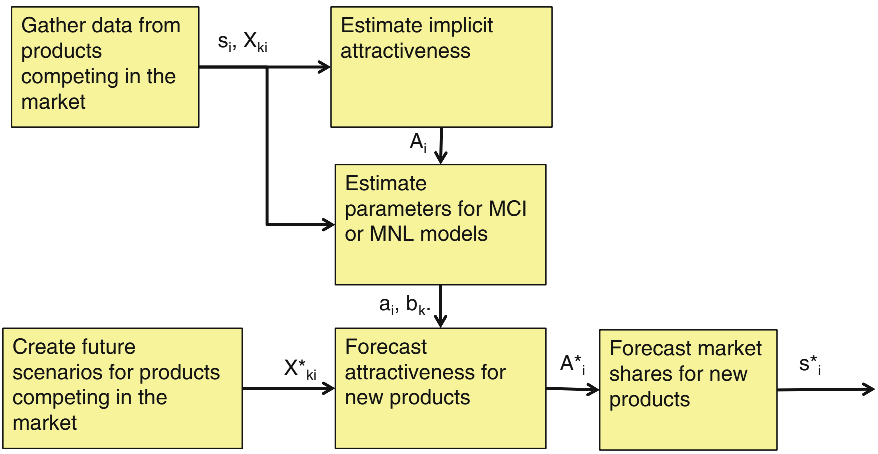


**Fig. 13.15** A flow chart showing the use of market share models in practice

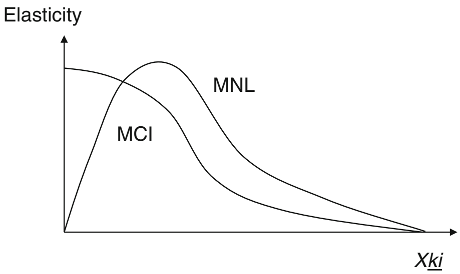


**Fig. 13.16** Elasticity of market share with respect to technical parameters in MNL and MCI

As shown in Fig. 13.16, elasticity tends to zero for values of $X_{ki}$ going to infinity for both MNL and MCI. This makes sense since, if one of the parameters $X_{ki}$ becomes extremely high, customers will progressively stop appreciating this increase, and the impact on market share will tend to become negligible. Instead, MNL and MCI differ when performance $X_{ki}$ is low. In the case of MCI, sensitivity is at first maximum and decreases with $X_{ki}$. This means that customers will greatly appreciate changes to $X_{ki}$ even if it starts from a very low level. On the opposite, sensitivity for MNL is at first very low, climbs to a maximum and then decreases. This means that customers will not appreciate changes to $X_{ki}$ when the value of the parameter is low, and will start doing so only when $X_{ki}$ becomes sufficiently high and exceeds a threshold level. Therefore, the choice between MNL and MCI depends on the nature of the parameters to be studied and on the possible existence of threshold levels.

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# Chapter 14
# Specifying the Product

Chapter 13 led us into the "front end" of the product development process, with a perspective that focused on the market. Readers should have left that chapter understanding how firms can interpret market needs and come up with a concise description of the product and of the market segment to address. Additionally, it has given insights on demand forecasting models, thus allowing a preliminary evaluation of a product's economic and financial attractiveness.

The product description so far generated is, however, inadequate for guiding designers' efforts. It is therefore essential to move on from the user needs gathered during market research into a more detailed compilation of *user requirements* and then—given a product concept—to *product design specifications* (or, in short, *product specifications*). A *user requirement** is a formal decision that a given user need is to be met by the product. While user needs are typically expressed in a qualitative way, requirements are defined at a definite and measurable level, without, however, telling how they will be technically fulfilled. A *product specification** can instead be defined as a list of product features, functions and parameters whose values are set so to comply with user requirements.[1]

In the previous definitions two elements are very important from a conceptual point of view, and must be highlighted. First of all, the transitions from need to requirement and from requirement to specification are not simple *translations*, but are the outcome of design *decisions*, since they could lead to many different alternatives.[2] Secondly, the step from user requirements to product specifications

[1]If one thinks about a simple product such as the remote control for a TV set, a user need elicited during market research may be "*I don't want to have to put my eyeglasses on when operating the remote control*". The firm may therefore decide to cope with this need by asserting the following requirement "*button labels must be readable in 50 lux (dim light) by a user having a visual impairment of—1diopters*". The requirement may then be translated into a specification such as "*characters for button labels must be at least 6 mm tall and must be color-contrasted with their background*".

[2]In the remote control example, it is up to the company to decide on the degree of readability of button labels with respect to illumination level and the degree of visual impairment, and to decide whether 6 mm tall and color-contrasted characters would adequately meet such requirement.



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_14

assumes that an underlying product concept has already been defined.[3] As mentioned in Chap. 11, most design activities deal with incremental innovations that will not substantially change the product concept. This being the case, firms will seamlessly move from the definition of user requirements to product specifications. This is the same approach that is being followed in the structuring of this book, which concentrates user requirements definition and product specification in this same chapter, while conceptual design will be discussed in the following Chap. 15. In the case of radical innovations, product specification and concept generation will instead overlap and possibly lead to iterations. We can therefore say that, when dealing with a radical innovation, the firm will implement the contents of Chaps. 14 and 15 in parallel.

The product specification phase is characterized by a number of challenges:

- The **interfunctional nature of the activities**. User requirements definition and product specification occur at the interface between the marketing and technical functions of the firm. Consequently, they bear all the difficulties that are inherent to activities carried out among professionals who come from different cultural backgrounds, and sometimes have completely different perspectives and objectives.
- The **quantity of information** being generated. Moving from a list of user needs to a set of user requirements and to a complete product specification usually entails generating a significant amount of information. Product specifications lists can be very long and complex, even for simple products. Companies often publish documents that list specifications for their products, either in data sheets or in user manuals. However, it must be noted that this public information constitutes only a subset of the entire product specifications list, which is published because of legal obligations, to help prospective customers choose the product that best suits their needs, and to allow users to make a proper use of the product.
- The **uncertainty of information** generated. During this phase, the firm makes decisions without yet having cleared the technical and commercial uncertainty that characterizes product development. When specifying the product, detailed design has not been carried out yet, nor does one know how specifications will propagate along the Bill of Materials into the specifications of each component. Therefore, user requirements and product specifications may either be technically unfeasible, or may be too lax, leading to a product with significant opportunities for improvement. Moreover, the specifications may not correctly interpret customer needs, resulting into a product with low attractiveness and disappointing returns.

[3]When defining character size for button labels, the designer is assuming that the remote control will be operated with physical buttons, which is only one of the many possible technical solutions allowing the required functions to be carried out (for instance, a remote control might be conceived with a touch screen-based interface).

- The need to cover all **phases of the product lifecycle**. Market research focuses on customer needs, but products follow a complex lifecycle and must therefore comply with the requirements cast by a variety of stakeholders. Aspects such as manufacturability, logistics, field service, and end-of-life disposal must therefore be adequately taken into account.
- The **tradeoff** between the stability of product specifications and the opportunity of adopting late commitment strategies. In theory, one might ideally wish to frame specifications clearly and firmly, with perfect adherence to technical feasibility and market needs, so that designers may operate on firm ground. In reality, and as discussed in Chap. 11, ambiguity, uncertainty, and change in the technological and market environment may require a different strategy. In these cases, a subset of requirements will be kept stable, while for other ones it might be advisable to follow a "late commitment" strategy, keeping options open and waiting for further information to emerge.

Given the above, a proper definition of product specifications can be considered to rely on appropriate information sources and on the use of a sound methodology. The following two sections will, respectively, deals with these two aspects.

## 14.1 Information Required for Product Specification

Product specifications are drawn from product briefs generated at the end of the market research phase, but must also rely on a broader variety of sources.

Preliminarily, the firm will often compile a *mission profile*. In fact, if the firm does not understand the usage the product will be subject to, it will be impossible to develop a product whose specifications will lead to the satisfaction of user needs.[4] Once the mission profile has been defined, the firm will draw information from a variety of sources, in order to address all areas that are relevant to the product and throughout its lifecycle (see an example in Fig. 14.1). It should be evident that the user needs coming from market research are central to this effort, but are not enough to draw a complete picture of specifications.

[4]For instance, suppose users of a high-end digital camera ask for a "reliable" product, where "reliability" implies a defined number of years before the product fails and has to be replaced. The manufacturer will probably view a connection between this need and the expected lifetime of the mechanical shutter, expressed in thousands of actuations. However, it will be possible to connect the requirement to a specification only if the manufacturer correctly defines the "mission profile" of the camera. In this simple example, the product brief might recite: "*this camera is aimed at photography enthusiasts and professionals who need a stand-in product along to their main camera*". The manufacturer will therefore have to define the number of yearly shutter actuations that can be expected to be made by the customers belonging to these two segments.

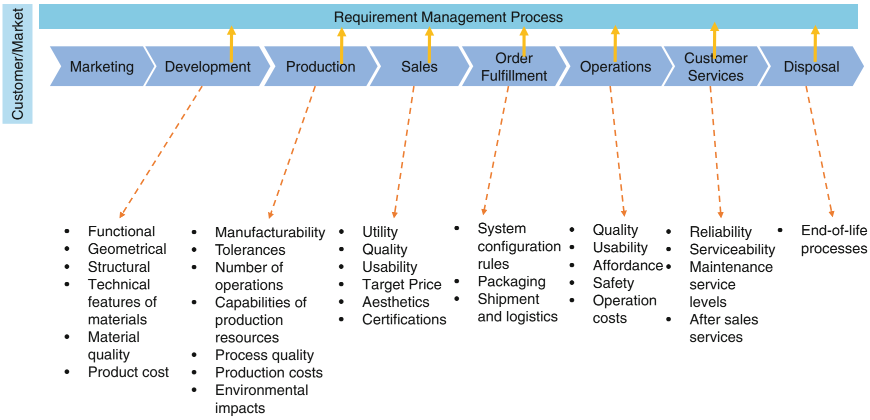


**Fig. 14.1** An example list of lifecycle requirements

In order to collect this information the firm may use:

- **Sources emerging from the industry**. Examples are trade journals and websites, together with suppliers' and competitors' catalogues. Competitors' products can be studied either "on paper" or actually purchased and reverse-engineered to provide detailed information.
- **Sources associated to the market**. Besides market research actions as described in the previous chapter, firms can rely on a variety of other documentation: reports published by consumer associations and independent entities, internal reports on customer feedback, warranty claims, etc.
- **Official sources**, such as boards issuing regulations that are relevant to the product (e.g., norms and standards), patent databases, etc.

In order to visualize the mass of information thus gathered, firms sometimes use parametric analysis on a subset of product features. Parametric analysis is based on the development of a product database going back some time in the past, and recording the values of the most relevant technical features for all products being sold on the market. This database can support intuitive visualizations of competing products and of their evolution in time. For instance (see Fig. 14.2a), one can plot the evolution of a single parameter in time, where each product is represented as a bar that starts in the year of launch and ends in the year of withdrawal. This allows identifying entry and exit of each competing product in each segment. Alternatively (see Fig. 14.2b), one can plot the evolution of two parameters at the same time. In this case, each product is mapped as a point, and the technological frontier at a given date can be represented by isochrones that include all products launched at that date. This graph shows the evolution of pairs of performance indicators, eventually identifying technical complementarity (if both grow together) or trade-offs (should growth in one be associated to a decrease in the other).

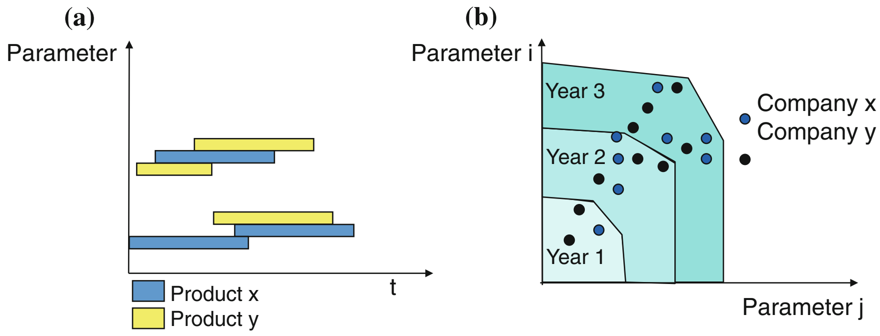


**Fig. 14.2** Parametric analysis allows the visualization of the way products evolve in time

Parametric analysis apparently resembles the strategic maps discussed in Chap. 13, but with the key difference that what is being monitored and visualized are technical features, and not high-level and tacit primary needs.

## 14.2 Acquiring Specifications Through User-Centered Design

One key subset of user requirements is associated to the usability of the product. It is in fact quite useless to develop products with many functions and substantial performance, if users are not in the position to fully exploit them. *User-centered system design* (or *user-centered design** in short, Norman and Draper 1986) can be viewed as the natural continuation of the user-centered product development approach outlined in Chap. 13.[5] In this previous context, the firm interacted with users in focus groups and participatory activities in order to highlight general needs associated to the product. Now, similar activities are used to provide fine-grained information to be used during the product design and specification phase. User-centered design is usually based on observing, reporting and detailing user interactions with the product. This leads to defining specifications with respect to interaction modalities and the *user interface** of the product. Since interaction between users and products is generally quite complex, it is common to make

[5]User-centered design actually merges three different design approaches, and namely *cooperative design,* from the Scandinavian tradition of design of IT artifacts (Greenbaum and Kyng 1991), *participatory design**, by the North American design school (Schuler and Namioka 1993), and *contextual design**, that connects customer-centered design to the actual circumstances surrounding the "use situation" (Beyer and Holtzblatt 1997). User-centered design has become a formalized procedure through the ISO standard "Human-centred design for interactive systems" (ISO 9241–210, 2010).

synthetic representations of typical usage patterns by developing *personas*, *scenarios* and *use cases*.

- **Personas** are fictional characters that embody the needs and traits of specific target users (or, in marketing terms, finely defined customer segments). Each persona is identified with a name, a set of demographic attributes, motivations and needs, so that designers can better immerse themselves in the idea that they are operating for the benefit of a specific individual, and not for an anonymous group of users. Designers may also work with multiple personas in order to better understand diversity in the user population and avoid thinking in terms of "average" users.[6]
- **Scenarios** are fictional narratives of the context in which the persona interacts with the product. Scenarios allow designers to frame the user-product interaction in a specific setting, thus achieving a deeper understanding of these events. One can frame multiple scenarios, thus introducing different types of situations and levels of ease.[7]
- **Use cases**. A use case is the detailed and step-by-step description of the interaction between the user and the product. Each step raises issues associated to usability, and can therefore influence requirements. The use case is generally represented in a graphical format, for instance, with a swim-lane flowchart (see the example in Fig. 14.3), which represents the sequence of actions undertaken by the user and the system. In some cases, it may be advisable to split the system in its components. At the least, this can be done by separating the *front-end* (i.e., the interface that the user interacts with) from the *back-end* (i.e., the portion that operates without direct user interaction). In the case of services, designers can develop a *user journey**, by using value stream maps. These maps represent the steps the user makes in interacting with the service and—again—one can distinguish between what happens in the *front-office* and in the *back-office* of the service, which are separated by the so-called *line of visibility* (Fig. 14.3).

According to Norman (1998, 2002), *usability* of a product can be improved by making a detailed analysis of user interaction. In general terms, interaction follows a process that can be structured around the seven phases represented in Fig. 14.4. When analyzing the interaction process, one must of course consider that users will usually perform it in a tacit and unconscious way.

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[6]For instance, one may define "*Marie, 35-year old IT professional, mom of two children (4-year-old Susie and 2-year-old Jean). She is the wife of Robert, an airline pilot who is often away from home. They live in an apartment in the XV Arrondissement of Paris*". Diversity may be increased by adding to the family "*Jeanne, Robert's 70-year-old mother, who lives close to Robert and Marie and sometimes borrows their car to visit her friends during the weekend*".

[7]For example, a scenario associated to Mary's usage of the family car might be "*Mary has collected her kids from school and now is in the grocery store's parking lot, having to move items from the shopping cart to the trunk of the car*". This scenario can be further split into a best-case scenario such as "*the sun is shining, the kids are happy and singing a song*", and the worst-case scenario "*it's raining heavily, the kids are crying and a phone call is coming from Singapore, where Robert is minutes away from taking-off for a long-haul flight*".

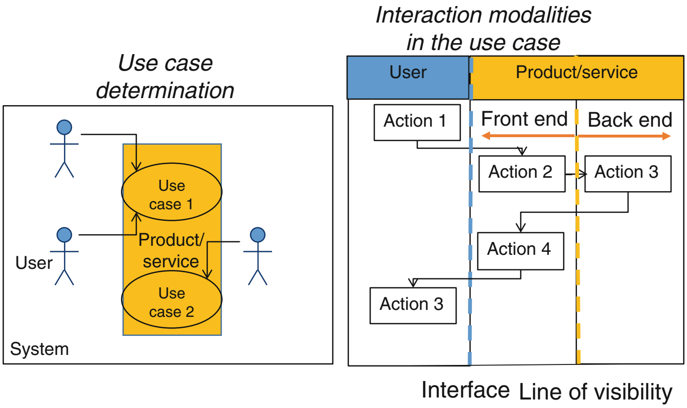


**Fig. 14.3** Using use cases and swim-lane diagrams to represent interaction modalities

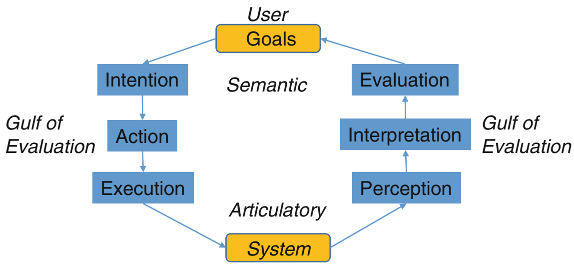


**Fig. 14.4** The interaction process according to Norman

According to Norman's model, users interact with a system with the objective of fulfilling a goal (e.g., operating an air conditioner in order to make a room comfortable and working in it). The process is made up of a first stream, which consists in evaluating the status of the system, and a second one, associated to executing actions. The former can be split in the three stages of *perceiving* the state of the system (e.g., looking at the air conditioner's control panel), of *interpreting* this perception with respect to expectations (e.g., obtaining information on whether the air conditioner is working or not and on room temperature and humidity) and, finally, *evaluating* the system state with respect to intentions and goals (e.g., making up one's mind on whether the room is at the right temperature or not). The latter stream is divided in the three stages of *forming the intention to act* (e.g., deciding on whether the temperature should be raised or not), of *specifying an action* (e.g., deciding to turn the appropriate knob in order to raise the temperature level) and, finally, of *executing* the action (e.g., actually turning the knob).

Norman highlights that each transition from one stage to another is associated to a cognitive difficulty, or *gulf*. The system and its interface are properly designed if each gulf can be easily bridged by the largest possible share of the target population. Conversely, a badly designed product is characterized by the fact that moving from one stage to another is difficult and/or error-prone.[8] For instance, if the air conditioner is extremely silent—which of course could be considered as a positive feature—the user may find it hard to perceive the state of the system, and some type of visual aid should therefore be provided. Similarly, the user may find it difficult to define the sequence of actions, if the knob does not clearly indicate the right direction to turn to increase the temperature. Finally, if the knob is too small and does not provide sufficient grip to fingers, the execution of actions may be difficult for users with some degree of physical impairment.

When studying usability, a particularly important concern is associated to the structuring of sequences of actions, especially when dealing with complex systems with many possible interaction modes. In such cases, designers must be aware that users might find it difficult to cope with the *breadth* and the *depth* of action sequences. A very broad range of possible alternatives (e.g., a webpage with dozens of links) may leave the user confused about which to choose. However, a narrow range of alternatives (e.g., a minimalistic webpage design with just two links) may leave the user with the impression that the desired action is not available at all, while in reality it might be accessible as a two-step sequence. Moreover, having to learn and perform a long sequence of actions to achieve the desired results may make interaction ineffective (e.g., think of the number of steps that are usually required to complete the purchasing process on e-commerce websites).

Based on extensive research on "good" and "bad" designs, Norman proposed a list of eleven design principles which can improve the usability of products. These principles can be used both in the early stages of product development, when defining user requirements and product specifications, as well as later, during the design phase. These design principles are summarized in the following Table 14.1.

When dealing with highly automated products (e.g., a robotic lawn mower, or automotive driver assistance systems, such as adaptive cruise control and lane departure warning) requirements and specifications must take into account the system's capability of acting autonomously from the direct control of users. In this case, instead of having a continuous interaction characterized by the user's issuing of commands and the system's execution, one can observe two relatively independent processes carried out by the two. Norman (2005) has studied also these types of product in depth, highlighting the role of different levels of reasoning and their allocation to the system. Basic automation can be equated to *visceral* reasoning, which is the unconscious behavior exhibited by humans, and that does not require a particularly sophisticated or specific learning. An example of visceral reasoning is a basic cruise control, able to keep a car running at constant speed. At a higher level, one can find *behavioral* reasoning, which humans mostly perform

[8] A distinction can be made between *slips* and *mistakes*, the former being errors in the execution of appropriate actions, the latter being errors associated to the very action to be taken. For instance, a slip occurs if a user that must press a button presses both the right one and—inadvertently—another one that is located too close. It would be a mistake if the user pressed the wrong button, having misunderstood the functions associated to it.

**Table 14.1** Design principles for usability, according to Norman (2002)

| Principle | Explanation | Example |
|---|---|---|
| Visibility | It must be easy to see the state of the system and the available controls | In an appliance, having an amber and green LED, respectively, indicating stand-by and operational state might be better than having a single one, indicating operational state only |
| Conceptual model | The system must help users understand how it works, taking into account that most people have limited technical knowledge and think in terms of "folk physics" | In the case of an on/off thermostat, many users will tend to overshoot the desired temperature, in the mistaken assumption that this will make reaching the desired temperature quicker. This is especially true if the system does not provide quick feedback |
| Mappings | Relevant relationships must be easy to determine, i.e., between indicators and system state, between controls and effects | If the layout of controls and indicators follows the physical layout of the system, users will find it easier to understand their meaning |
| Feedback | The system must provide accurate and quick feedback on results of actions. | A button that "clicks" when depressed tells the user that the command has been received, while a silent one does not. |
| Affordance | The mode of operation of a given control should conform to the general understanding of how it works | If a user sees a knob, he or she will assume that it should be turned, clockwise to "close" and counterclockwise to "open" something. It could be puzzling to the user if a knob had to be pushed or pulled |
| Information in the world | Relevant information should be provided directly by the system, without requiring users to make any specific effort in learning or remembering | Controls and indicators with labels and pictograms that are easy to understand can make a product easy to use without any specific instruction |
| Do not require precision | The system should allow users to operate with imprecise knowledge, data, or actions | Buttons should be spaced from one another and shaped in a way that they accommodate the users' fingers, so that they are not pressed by mistake |
| Use constraints | The system should use physical and cultural constraints to induce into correct behavior | If an action moves the system state in a dangerous situation (e.g., very hot water in a shower), the device should provide some kind of resistance to make the user aware of the issue |
| Design for a variety of users | Designers should take into account that users vary widely with respect to technical understanding, physical traits, and abilities | The size and coloring of labels and pictograms on commonly used devices should be such that users with moderate presbyopia do not have to put their eyeglasses on |

(continued)

**Table 14.1** (continued)

| Principle | Explanation | Example |
|---|---|---|
| Don't forget users | Companies generally focus on customers and other stakeholders, but users should never be neglected | Industrial equipment is bought by plant managers, but adequate attention should be paid to usability by the operators |
| Feature creep | Designers tend to overload products with functions that are often unnecessary and ultimately make the product difficult to use. Additional features should be inserted progressively and, if possible, through modularization | Software packages generally allow hundreds of functions, a tiny portion of which is actually used. A correct strategy might be to provide a base package and a set of add-ins catering to specific needs |

unconsciously, and requires significant learning. For instance, one may consider the ability to continuously manage the velocity of the car in order to chase a speed target set by the driver, taking speed limits and safety distances into account. Finally, *reflective reasoning* is the higher-level and conscious activity carried out by humans, associated to purpose and objectives. An example would be a self-driving car, capable of choosing the right itinerary, given a destination, objectives, and knowledge of traffic conditions and road quality.

According to Norman, the assignment of these three cognitive levels to the system must not be rigid, but flexible. In other words, the user must be in the position of yielding greater control to the system in normal conditions but—should conditions require it—she must be able to quickly regain complete command. As an analogy, it is possible to think of the interaction between a horse and a rider. When returning to the stable after a promenade, the rider can let the reins loose, and the horse will autonomously take her back home, assuming all three levels of reasoning. However, in case of danger, the rider will take the reins in, and regain tight control over the mount's behavior. As with horses and riders, an effective "symbiosis" between user and machine will emerge if the designers are able to create an appropriate pattern of communication between the two, striking the right tradeoff between the provision of a rich set of information and information overload. Within this pattern of communication, a distinction can be made between *task automation*, in which the system assumes control, and *augmentation*, in which the task remains with the user, but with some support from the system, aimed at relieving part of physical or cognitive load.[9]

[9]For instance, a self-steering car capable of keeping the same lane with unpredictable traffic could be currently difficult to develop from a technical and regulatory perspective. Current lane assist systems therefore *augment* drivers' perception by providing feedback if the vehicle leaves the lane, for instance by making the steering wheel vibrate. Such feedback must of course be easy to interpret (e.g., a buzzer would not fully meet this criterion).

## 14.3 Analyzing the Requirements of Multiple Stakeholders

When moving from B2C (Business-to-Consumer) to B2B (Business-to-Business) markets, and especially in the case of radically innovative products, the definition of customer requirements becomes a complex problem to solve. With B2C products, the purchasing process is relatively simple, with an individual buyer and seller finding mutual benefit from the proposed transaction. In B2B, instead, the purchasing decision is not a simple event, but a complex process in which multiple stakeholders appear, act and mutually influence themselves. Therefore, a product will be successful only if all of these stakeholders will favorably align their attitude toward its introduction. This requires the producer to understand the purchasing process in detail and design the product accordingly.

In order to frame this problem in a systematic way (Cantamessa et al. 2012; Cascini and Montagna 2014), it is possible to identify four stakeholder types and three main situations in which they act (Fig. 14.5). Stakeholders can assume the role of *customers* (i.e., the actors who have formal authority over the purchasing decision), *users* (i.e., the actors who will most extensively and actively interact with the product), *beneficiaries* (i.e., those who receive benefits from the use of the product and/or interact with it in a passive way) and *outsiders* (i.e., any other affected party). The three former stakeholder types are directly involved in the purchasing process, while the latter one rarely influences it.

Concerning situations, the first is *purchasing*, which is done by customers. The second is *delivering benefits*, which is associated to usage (e.g., a doctor *uses* a surgical instrument and the patient *benefits* from this). The third is *creating externalities,* i.e., the effects that propagate beyond the direct beneficiaries.[10] This basic way of framing the problem may be used as a starting point for further elaborations, in case of complex purchasing processes.

Each of these stakeholders operates according to a set of specific needs and ascribes importance levels to these needs. Needs can emerge from the actor itself (*native* needs) or can be the result of influences cast among actors (*reported* needs). Mutual influence therefore generates reported needs and alters the importance or the perception that an actor assigns to native needs.[11]

For the producer, the ability to understand and proactively work on multiple stakeholders' needs and their mutual influences is integral to defining requirements

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[10]For instance, in the case of a public transport bus, the buyer is the purchasing office of a municipal transport authority, the users will be the employees, such as bus drivers and maintenance crews, and the direct beneficiaries are the passengers who buy tickets and ride the bus. External beneficiaries include citizens being affected by the emissions of the vehicle, or pedestrians who may be impacted by the bus—quite literally in fact—in case of an accident.

[11]Referring to the public transport example, it is obvious to assume that—all the rest being equal—managers will prefer a bus that minimizes harmful emissions, even without being directly influenced by citizens. However, the importance that management will attach to this need may be altered if citizens actively cast such an influence through a citizens-rights association.

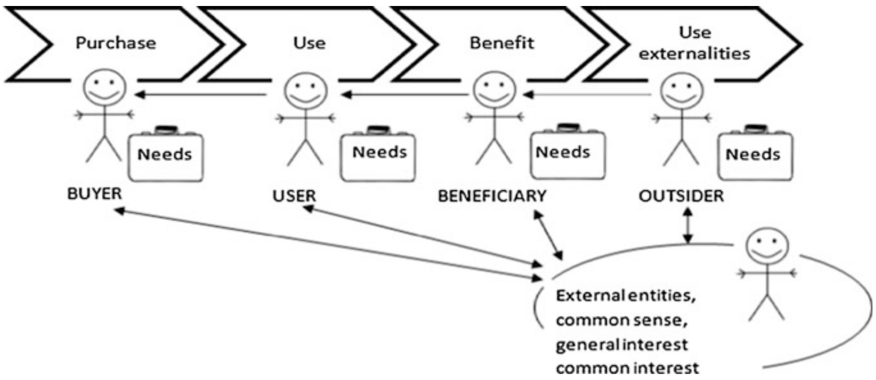


**Fig. 14.5** Stakeholders involved in the purchasing and usage process of B2B products

and specifications. This will lead to the design of the product and also to the definition of its go-to-market strategy.[12] Requirements must take into account stakeholder needs in such a way that all actors who are involved in the adoption decision see their needs being met at a degree that is that is sufficiently compelling for each of them to decide in favor of the product and agree to it.[13]

In first approximation, a firm may analyze the purchasing process in a qualitative way and simply come out with a list of requirements coming from the various stakeholders. If a more rigorous approach is needed to negotiate among the many potential conflicts and tradeoffs, it is possible to use methods derived from Actor Network Analysis (Cantamessa et al. 2013).

## 14.4 Quality Function Deployment

User requirements and product specifications can be defined following a variety of methodologies. Sometime these methodologies are closely linked to company-specific or industry-specific standards. In this context we will present *Quality Function Deployment** (or QFD), which is a methodology that is widely used across industries either in its original form or in many adaptations.

[12]We have often observed salesmen interact with the product development team and ask "*the features you are proposing for this product are cool, but how are we going to sell it?*".

[13]For instance, a new bus that comes with a powerful but difficult-to-use IT-based fleet management system will probably not be adopted, because drivers will object to the procurement office and oppose the purchasing decision, or may simply avoid using it once it has been bought. Conversely, a system that is user-friendly but expensive will probably be vetoed by managers even if drivers push for its adoption, unless the latter are able to show that it will lead to financial benefits that out-weight the additional cost.

QFD was developed in Japan in the ‘70s as a design support tool aimed at clarifying user needs and enabling their translation into coherent product specifications. Later on, it became one of the key techniques being proposed by the *Total Quality Management** movement for ensuring that the *voice of the customer** could be adequately “heard” within the product development process. According to its principles, QFD should be used to support the entire development process, from the initial phase of requirements definition and product specification, all the way to the design of manufacturing processes and quality assurance systems. In practice, surveys have shown (Cristiano et al. 2000) that most companies use it in the initial phase of the development process only. Literature on QFD use (Akao and Mazur 2003) has shown that the technique is indeed beneficial, especially with respect to the decrease and the anticipation of engineering changes, which has an obvious and beneficial impact on product quality, as well as on development cost and time. At the same time, it has been shown that QFD essentially is an organizational tool that allows a better understanding and improved communications across corporate functions. Therefore, the method should not be treated as a tool for automated decision making, while it should be kept in mind that successful application depends on the goodwill with which its users engage in this translation process.

In practice, the main idea behind QFD is to develop incidence matrices called *Houses of Quality* that link the inputs, listed in the rows of the matrix, and the outputs, listed in the columns. Each translation step in the development process requires a separate House of Quality, as shown in Fig. 14.6. This allows the translation of user requirements into product specifications, and then to cascade them into component specifications, process specifications, and quality assurance specifications. The four steps follow the same principles and, since the process is seldom carried out in its entirety, we will describe the first House of Quality only.

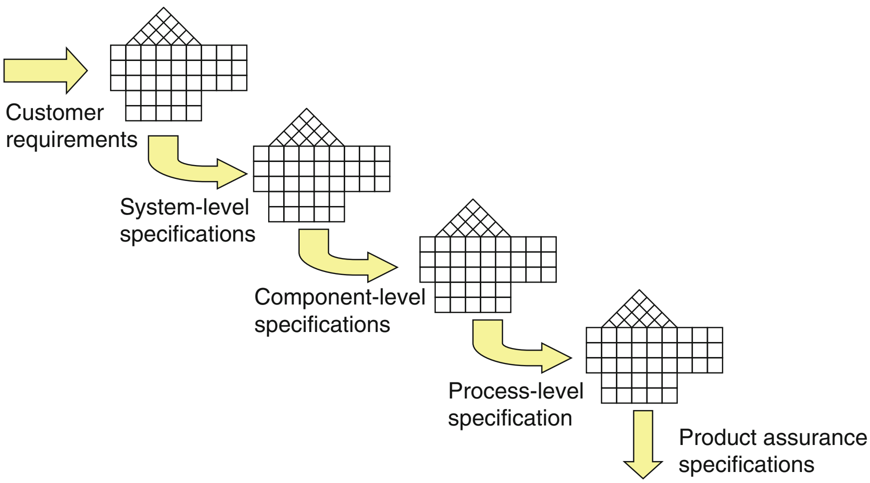


**Fig. 14.6** The quality function deployment process

A House of Quality is typically structured around the sections outlined in Fig. 14.7. The following discussion describes the typical information that is recorded, but firms are of course free to make the changes they find suitable for their products.

- **Customer requirement analysis** is carried out on the horizontal part of the House of Quality, usually under the leadership of the marketing function. The *m* requirements are listed on the left-hand side, while the detailed analysis is performed on the right-hand side. The first column in the analysis part is an evaluation of the average importance of each customer requirement $ICR_i$, indexed on the set $i = 1 \ldots m$, usually with a rating in the range [1…5]. User requirements and their importance ratings should ideally come from market research, since a development team being asked to “estimate” weights for user requirements will unavoidably draw from their specific experience, which may be very far from what actual target customers really feel and look for.[14] By referring to market research activities discussed in Chap. 13, it can be considered appropriate to use secondary needs in this context, because their number is manageable and since surveys generally provide quantitative information on the related ratings.[15] Working on primary needs would be of no use, since these are too few and are not detailed enough for supporting the definition of requirements (in fact, the purpose of identifying primary needs is to come up with a high-level market positioning for the product). Working on tertiary needs would instead lead to a very long list, the importance of which would be difficult to assess in an objective way. However, the development team might justifiably decide to break down specific secondary needs at a finer level of detail.

The following columns on the right are used to develop competitive benchmarking in a selection of currently competing products $k = 1 \ldots p$, the first of which is usually the current product being offered by the firm. Benchmarking is made by computing the average rating with which users perceive each product *k* to satisfy each requirement *i*, $RC_{ik}$. These ratings too ought to be obtained through objective surveys, and not by casting subjective assumptions within the development team.

Based on this competitive benchmarking, the team can define a set of target ratings $TR_i$ for the new product being developed, one per each of the customer requirements. This decision points to the areas of improvement the development team will have to work on, in terms of customers’ perception of the product. The importance that the development team will have to give to each customer

[14]The bias emerges because product developers usually have a technical competence and an inclination for technology that is far superior to users’. Moreover, the target customer segment can be significantly different from the one that the product development team is used to consider (e.g., a team that has to develop a new car model for a geographical market in which the team has no prior experience).

[15]It is probably appropriate to remind that these average ratings should not be computed on the entire sample used for market research, but only on the subset of respondents that can be associated to the customer segment the product is being targeted to.

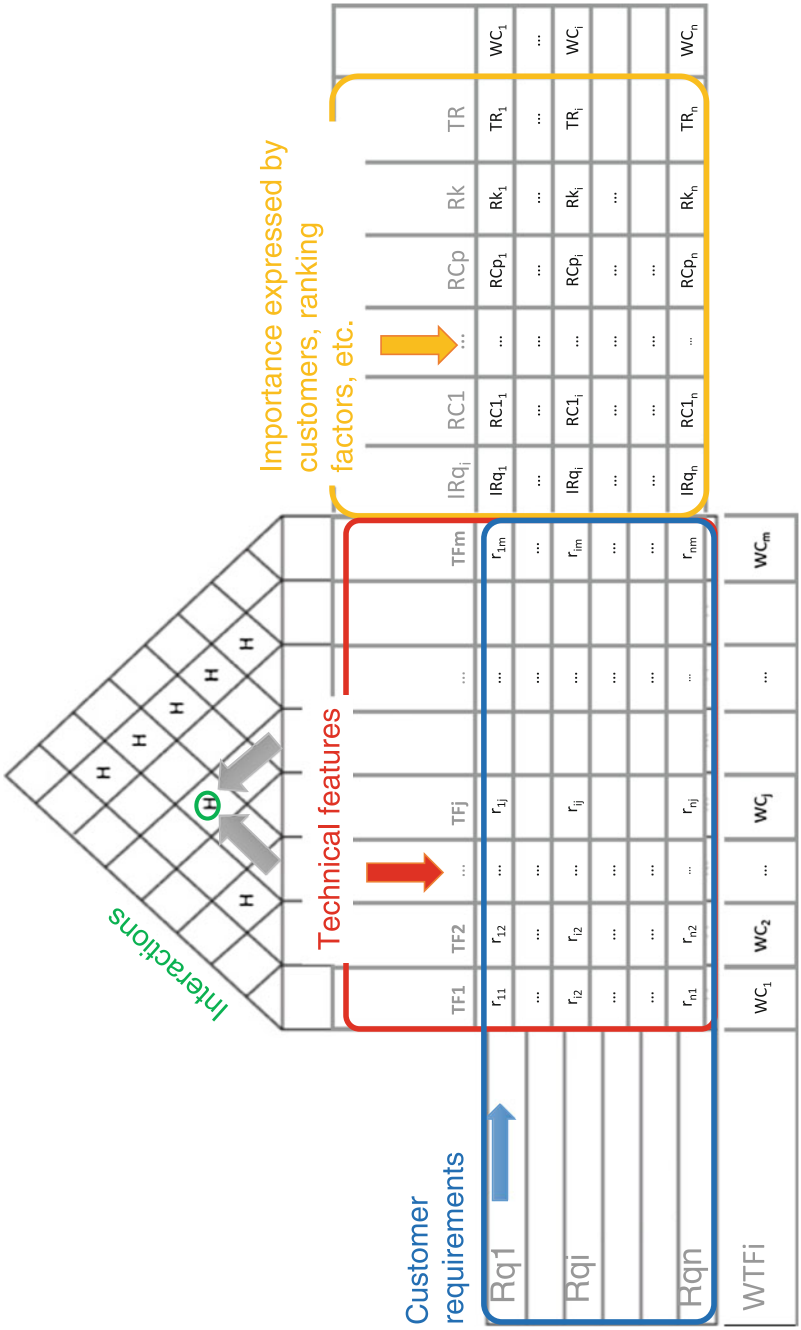


**Fig. 14.7** The structure of a typical house of quality

requirement, $WCR_i$, is then computed as an absolute importance weight, which brings together the importance that customers assign to the requirement and the improvement that the new product must bring with respect to the current one:

$$WCR_i = ICR_i \frac{TR_i}{RC_{i1}} \tag{14.1}$$

In some cases, importance weights $WCR_i$ may be further altered by multiplying them by additional factors. For instance, the firm may wish to increase the weighting of a few customer requirements for which it is easier to communicate improvements to the market, thus translating them into increased sales. In this case, a "bonus" of 10–20 % may be added to the weights of these particular requirements. For simplicity, importance weights $WCR_i$ are then normalized $WCR'_i$, so that their sum adds up to 100.

- **Technical features definition** is carried out on the vertical part of the House of Quality, usually under the leadership of technical functions. A list of $j = 1 \ldots m$ technical features are placed at the top of the matrix, at an appropriate level of detail. These technical features must in fact be easy to relate to product-level customer requirements, but must not be so generic that they cannot be measured.[16] The technical team will then collect values of these technical features from the same panel of products for which a comparison was made during customer requirements analysis.
- **Technical features weighting**. At this point, the development team can relate customer requirements to technical features, in order to understand how the weights given to the former lead to priorities concerning the latter. At first, one must define the strength of the relationships $r_{ij}$ between each customer requirement and each technical feature. These relationships, which are placed in the central part of the House of Quality, express the degree with which customer requirement $i$ is affected by technical feature $j$. These relationships are usually expressed on the basis of expert judgment, using a {0, 1, 3, 9} scale, where 0 means "no relationship", 1 a "very weak" relationship, 3 a "weak" relationship, and 9 a "strong" relationship. This scale may seem to be quite arbitrary, but it is quite effective in discriminating technical features that are essential to the fulfillment of customer needs from the ones that are not so important. At this point, it is possible to compute a weight for each technical feature, $WTF_j$

$$WTF_j = \sum_i r_{ij} WCR'_i \tag{14.2}$$

[16]For instance, in a passenger car it makes sense to specify maximum speed and acceleration, but not engine horsepower and torque, which would be the corresponding specifications at engine level.

Weights $WTF_j$ can also be normalized to $WTF'_j$, so that their sum adds up to 100.
Thanks to this exercise, the design team now has a clear indication of the importance that each technical feature has "in the eyes of the customer" and according to the improvements that are needed to make the product more attractive. These weights can therefore provide guidance for the definition of target technical features for the new product. Specifically, more ambitious targets will be set for those technical features which carry a higher weight.

- **Relationships between technical features**. Quite often, the House of Quality is enriched by a further section that is located on the triangular "roof", above the list of technical features. In this section, the product development team can place information on relationships between technical features, using a parameter in the range [−M, …, + M]. A negative relationship will indicate a technical tradeoff, while a positive relationship implies that an improved value on one technical feature makes it easier to improve the other. For simplicity, relationships can also be indicated by using the discrete set $\{-1, 0, 1\}$. This information is usually quite well known to engineering designers, since technical tradeoffs are at the heart of their work. However, it may be interesting to make it explicit, thus making sure that it is properly documented and made visible to all components of the team.

From the description made above, the pros and cons of QFD should be quite evident. Looking at drawbacks, QFD clearly rests on quite weak methodological basis, since the algebraic tools with which priorities on customer needs are computed and then translated into priorities for technical features are quite disputable (Franceschini and Rossetto 2002). Specifically, the method relies on a number of judgmental indicators that are inherently based on ordinal scales and—as such—are ill suited to be treated as real numbers. On the positive side, QFD is a simple and powerful tool for rationally collecting, communicating and connecting the elements that define a product from the two perspectives of customer requirements and technology. By enforcing discipline into the specification of technical features and making sure they are *somehow* connected to customer needs, QFD is indeed a valuable tool in the hands of interfunctional product development teams.

## 14.5 Product Costing

### *14.5.1 Traditional Costing and Target Costing*

Cost estimation is a key element of the product development process, and it obviously impacts the firm's performance. It should be intuitive that inaccuracies in this activity can lead to mistakes that have strategic relevance, since an underestimation of costs leads to financial losses, while an overestimation will lead to a high price and the loss of market opportunities.

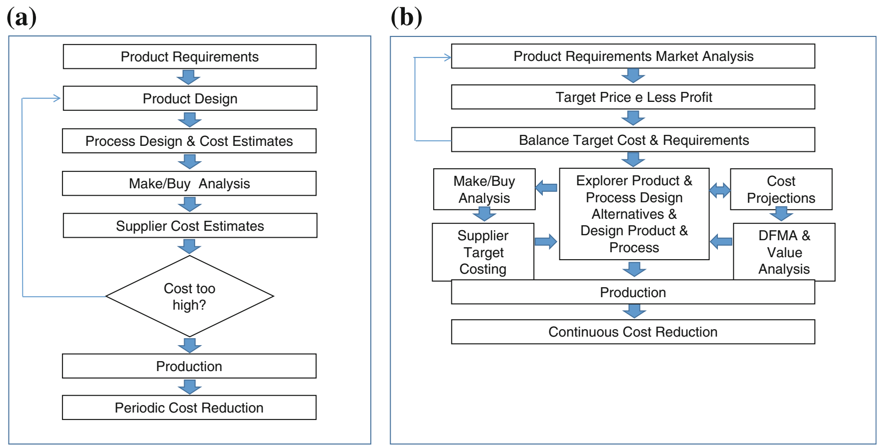


**Fig. 14.8** The traditional (*left-hand side*) and target costing (*right-hand side*) approaches

Depending on the approach being followed, it is possible to view cost as either a dependent or an independent variable of the product development process. If one follows a somewhat traditional approach, cost will be treated as a function of the technical features that define the product. In this case, cost is studied and managed according to the flow chart on the left-hand side of Fig. 14.8.

Once product requirements have been defined, product cost is estimated in a relatively rough way and then, as product design evolves, it is computed more precisely. If, at any given point, the firm realizes that cost estimates are becoming too high with respect to the future competitiveness and profitability of the product, this will lead to an iterative modification of product requirements, until cost becomes acceptable again. After product launch, the firm will run cost reduction initiatives periodically, or when market conditions require it. This approach has the drawback of viewing cost as secondary feature, and managing it only if it exceeds limits that are, however, defined in a somewhat arbitrary fashion.

The alternative approach, termed *Target Costing**, is depicted on the right-hand side of Fig. 14.8. Product requirements are immediately matched with a *target price*, which is estimated as the price that customers would be willing to pay for a product with these same features. Target pricing is usually defined by comparing the new and improved product with the existing one, and then estimating customers' willingness-to-pay for these improvements. In some cases, and especially when dealing with B2B products, the target price can be computed by considering the benefits the product provides to the customer, and assuming that customers are able to objectively quantify them.[17] Given the target price, the firm applies a desired

[17]For instance, a firm may set the price of a product by computing the annual savings or profits P it determines on a customer firm, and hypothesizing that customers will purchase it if its price $PR \leq P\ PBT$, where PBT is a payback time.

contribution margin, thus deriving the *target cost*, which then becomes one of the product specifications. The target cost is then divided into subsystem-level target costs, which will drive the development of each subsystem and component. In the case of products that are incremental improvements of existing products, the target cost must be allocated by keeping the sources of improvements into account. The team will then allow a higher target cost than the current one, to those subsystems whose improved performances are leading to an increased target price. Conversely, the same (or even a reduced) target cost will be imposed for the subsystems that are essentially unchanged.

For instance, Fig. 14.9 shows a stylized example of a passenger car, with the three main subsystems “body”, “powertrain” and “infotainment functions”. We can suppose the new model is improved over the previous one because of greater fuel efficiency and richer infotainment functions, and that market research assigns a price premium of 500 € for the former improvement, and 1.000 € for the latter. The development team will allocate target costs to the three subsystems by following the logic of “added value”, as shown in the picture. In doing so, it might happen that a higher target cost may amply accommodate the required technical improvements in one subsystem (e.g., for the infotainment system) but not in another one (e.g., for the powertrain). The development team should as far as possible resist a further renegotiation of cost allocation between the two subsystems. In other words, it should accept that some of its suppliers (or internal functions) might earn higher margins, and not be afraid of engaging in tough negotiations with the ones that provide low added value. This is an important element of target costing, whose underlying logic is that cost should follow value creation. If one takes a long-term view, granting some added profitability to suppliers who create significant value cannot be but beneficial, since this will improve future relationships and their capability of creating further value by reinvesting profits.

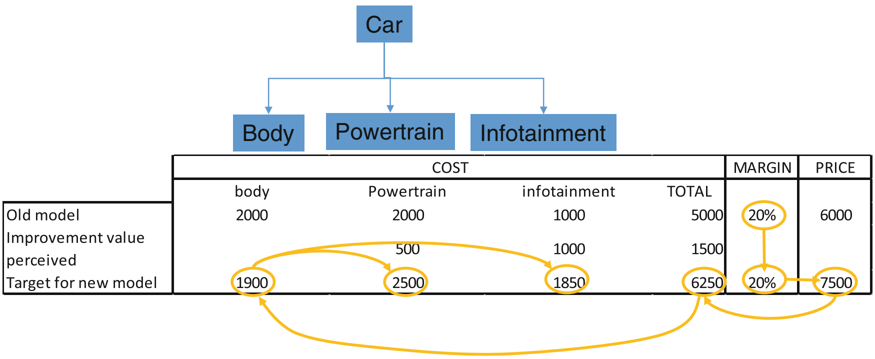


**Fig. 14.9** An example of target costing

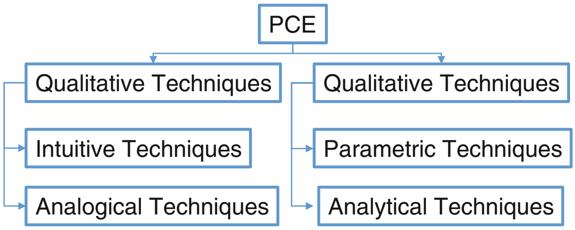


**Fig. 14.10** A classification of product cost estimation methods (from Niazi et al. 2006)

## *14.5.2 Cost Estimating*

Literature presents many contributions on methods for *Product Cost Estimation* (PCE). Niazi et al. (2006), as shown in Fig. 14.10, propose a hierarchical classification that explores all the possible methodological alternatives for cost estimation of components and/or the entire product.

Qualitative methods are divided into intuitive and analogical, the former ones based on rules, while the latter ones are based on exploiting similarities with existing products. In fact, products being developed are generally quite similar to existing ones, save for given areas of improvement. By analyzing historical data on previous products, and by focusing on the "cost of improvements", the design team may come up with a relatively accurate estimation of the costs of the new product.

Quantitative methods are categorized into parametric and analytical. Parametric models consider cost as a function of specific product variables (e.g., geometry, volume, etc.) that drive the economics of a product and its process.[18] These models can be developed bottom up, based on a detailed analysis of the process plan of the component and its cost structure. Alternatively, they can be developed by following a "black box" approach, by creating a database of components and then searching for statistical relationships between relevant features and cost. Analytical models are based on a relatively detailed description of the product, which leads to a greater precision in the cost estimate. Specifically, the Activity-Based Costing (ABC) approach identifies cost drivers not by looking at product features, but by focusing on the activities and the resources involved in the process (Tornberg et al. 2002; Park and Simpson 2005). In order to have a more precise estimate, or whenever there is not enough experience in similar components or products, cost estimation must be performed by actively involving the actors that are likely to supply the part. This means issuing a *Request for Quotation* (RFQ) based on a preliminary technical description. Internal departments of the same firm or suppliers

[18]For instance, parametric models can be based on rules such as "*surface treatment X costs 22 €/*m$^2$", or "*with technology Y, the cost of producing parts like this is about 12 €/*cm$^3$*, adding 2 € per each geometric feature to be machined*".

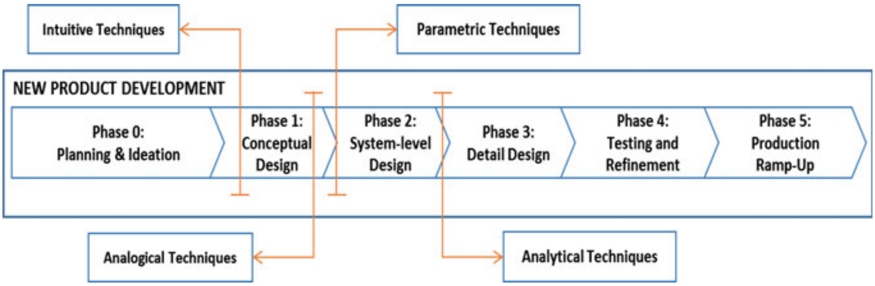


**Fig. 14.11** Use of cost estimation techniques in the product development process

will then respond to the RFQ with preliminary bids that—depending on the case—might or not be binding.

Choosing one cost estimation method or the other depends on the goals, on the decisions to be made, and on the surrounding uncertainty. Exact product costs can be computed only at the end of the product development process, when production is effectively started. However, firms must make estimates on product cost as early as possible, when preliminary choices are being made, and even before any design activity has actually taken place. Therefore, the choice of the method will be influenced by the stage of the design process and by the amount and quality of data that has been collected, as shown in Fig.14.11. Qualitative cost estimation techniques are usually appropriate during the early stages of design, as they are based on the comparison of the new product with previous ones, using historical data, past design experience, or manufacturing knowledge. Instead, quantitative techniques provide more accurate estimations, and their usage is often restricted to the final stages of the development process, when detailed information on product features, manufacturing, and service processes are available.

When estimating costs, care should be given in providing a precise definition of the elements that make up overall cost. Specifically, one should be able to distinguish between *variable* and *fixed*, and between *direct* and *indirect costs*. Readers ought to refer to cost accounting textbooks for a detailed description of this topic. However, just to provide a few essential definitions, fixed costs include costs whose overall value does not change when production volume varies. Conversely, variable costs are the ones whose total amount changes proportionally with production volume. It should be noted that fixed costs are never such in absolute terms, but only in reference to a given production range.[19]

On the other side, direct costs can be directly attributed to the good or service, while indirect costs are associated to activities or items that are generally enablers of the production process, but do not directly intervene in it. The classification of a cost as direct or indirect is not only related to its nature, but also to the ease with

[19]For instance, a die used in an injection molding process will be a fixed cost up to a given production level. After that threshold is passed, the firm will have to invest in a second die.

**Table 14.2** A few examples of costs and their allocation to cost categories

| Type of costs | Direct costs | Indirect costs |
|---|---|---|
| Variable costs | Materials used in making a product | Cost of ordering raw materials by the purchasing department |
| Fixed costs | The cost of machinery used to produce a part | Cost of the building where manufacturing takes place |

which the firm would be able to trace the actual usage of the corresponding activity or asset to a specific product. The following Table 14.2 provides a few examples of costs and their classification according to the direct/indirect and variable/fixed costs categories.

In general, firms use a simple job costing approach based on the following three elements

- **Direct material cost** includes all the costs associated to the materials used to make the component. This requires accounting inefficiencies such as scrap material, disposal of residual material, etc. Direct material cost is by definition direct and is obviously variable.
- **Direct labor cost** includes the use of personnel who is directly engaged in the production process. It is given by the hourly salary rate of such personnel, multiplied by the time they are engaged in this activity. In general, direct labor costs are treated as variable, in the assumption that staffing can be varied according to demand and/or that personnel not being used for a given product can be diverted to other types of production. There might be cases in which they should be treated as fixed (e.g., a manufacturing cell that requires the continuous presence of a supervisor, regardless of production volume).
- **Use of assets**. A distinction can be made between indirect, generic direct, and specific direct assets. Indirect assets, such as the building in which production occurs, is generally treated as a fixed and indirect cost, being part of what is called an overhead cost pool. Costs in an overhead cost pool will generally be allocated to the product according to some *cost driver.*[20] Generic direct assets include general purpose machinery that is directly involved in production (e.g., a metal stamping press that can be used for any part requiring this technology). This is a direct cost that can be treated as either variable or fixed, in the former case assuming that this asset will be used at saturation level by the firm. Such a cost will generally be considered by defining an hourly rate, given by the annual cost of the machine (including depreciation, maintenance, etc.) divided by the budgeted production hours. Finally, specific and direct assets are the ones that require an investment and that can only be used for manufacturing the specific

[20]For instance, if the cost driver used is direct labor hours, the firm will first compute the total annual cost of the overhead cost pool, *TAC*, and the total labor hours worked, *TLH*. It will then determine an "overhead rate" of *TAC/TLH* €/hour, which will be added to the direct costs of the product.

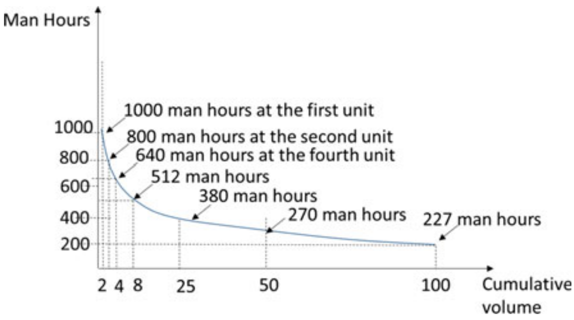


**Fig. 14.12** The evolution of product cost observed by T.P. Wright

product (e.g., the die made for processing a given part on the metal stamping press). This cost is direct and fixed, within the range of production volume that can be made with the asset.

## *14.5.3 Cost Estimating with Learning Effects*

### 14.5.3.1 The Learning Effect

As it has been mentioned in previous chapters, production cost is usually not constant over the product life cycle. As experience builds up, personnel engaged in production will progressively discover inefficiencies and propose improvements to the product and to the process, thus reducing costs. These improvements may in principle be connected to all of the elements that make up product cost, from the use of direct materials, to the man-hours and/or machine-hours that are required to complete production.[21]

This phenomenon has been studied by the proponents of scientific management since the beginning of the twentieth century, but a major contribution came in 1936 from T.P. Wright, who was working in the aircraft manufacturing industry. Wright observed that the time and cost required for producing an airplane decreased in time. However, he also noticed that this learning effect could be modeled more precisely by relating it not to time but, rather, to production volume. By rearranging data according to cumulative production volume, he realized that the data would neatly fit around a regular curve *similar* to a hyperbole or a negative exponential (Fig. 14.12). By displaying data on logarithmic scales, the phenomenon closely

[21]A difference is sometimes made between *learning effects* and *curves* (Wright 1936) and *experience effects* and *curves* (Henderson 1974), the former related to labor productivity and the latter to overall efficiency. The two phenomena follow mathematical models that are equivalent, and we will therefore consider the two interchangeably in the following discussion.

followed a straight line, which suggests a slightly different mathematical model that will be explored in detail in the following subsection.

When estimating production costs, neglecting the learning effect can lead to serious strategic errors (Henderson 1984). For instance, one can imagine an engineering company making a bid for the design and production of a large batch of components. A precise estimation of future production costs is essential both to win the bid and to ensure profitability. In fact, should the firm neglect the "experience curve effect", it will quote a price that will be significantly higher than the one proposed by a competing firm that does consider it, and the contract will be lost. However, should the firm be overconfident of its capability of progressively reducing costs, the price quoted will be very low and will very likely lead to a winning bid. However, should the expected cost reduction not materialize, the firm might be forced to supply the parts at a loss.

The experience curve effect has strategic implications also for firms that are engaged in an open market, where market share depends on product quality and price. Firm X may be very conservative in considering the experience curve effect, and therefore decide to price its products according to a cost-plus approach, progressively lowering the price when it realizes that cost is indeed decreasing. On the opposite side, another firm called Y may make an aggressive move, based on its forecast of cost reductions tied to experience. Y will therefore start with a low price, sometimes accepting that margins may initially be negative, in the expectation that this low price will determine higher market share and demand and that this large production volume—in turn—will drive costs down. Such a move can lead to major strategic benefits, especially for markets characterized by first-mover advantage. Firm Y will also enjoy competitive advantage with respect to competing firm X which, not having followed the same strategy and having been left behind in the experience curve, will have no way to recover. Of course, the impact of an aggressive pricing behavior based on the expected experience curve will also depend on competitors' behavior (Gilbert and Lieberman 1987). If X and Y simultaneously follow the same strategy, the outcome will be a low price, with no gains in market share for any of the two firms, and a consequent lower-than-expected decrease in costs. As a matter of fact, the profitability of many capital intensive industries is routinely undermined by this type of behavior (Armstrong and Green 2007).

#### 14.5.3.2 The Boeing–Crawford Experience Curve Model

As discussed above, empirical analysis has shown that cost reductions as a function of volume usually show up as a straight and downward sloping line, if the two variables are plotted on logarithmic scales. The corresponding model, which is generally known as the Boeing–Crawford[22] experience curve, therefore is:

[22]For a review of learning curve models, readers may refer to Anzanello and Fogliatto (2011).

$$C(n) = C(1)n^{-b} \tag{14.3}$$

where:

- $C(n)$ is the cost of the product being manufactured or, depending on the case, a portion of the total cost that is subject to learning effects. Alternatively to cost, one might consider the time required to manufacture the part. This cost is viewed as a function of cumulated volume, so that $C(n)$ represents the cost of the $n$-th part that has been produced (one might therefore consider it as a marginal cost when moving from the ($n-1$)th part to the $n$-th);
- $b$ is called the learning rate, and represents the rate with which costs decrease;
- $C(1)$ is the cost of the first part

If one takes logarithms, (14.3) becomes (14.4), which is clearly a straight line whose downward slope is given by $b$.

$$\ln C(n) = \ln C(1) - b\ln(n) \tag{14.4}$$

Because of the linear relationship on a log–log scale, it is straightforward to use linear regression in order to identify parameters from empirical data. However, it would be misleading to use the actually recorded cost of the first part for $C(1)$, and therefore use the regression to identify $b$ only. The reason is that the cost of the first part is subject to many possible incidental factors, which might lead to unexpectedly high or low values. Secondly, it has been noticed (Li and Rajagopalan 1998) that experience often suffers from a "decay factor" due to obsolescence of knowledge and employee turnover. This decay can be modeled with a parameter $\delta < 1$, which decreases the impact of cumulated volume, so that (14.3) becomes

$$C(n) = C'(1)(\delta n)^{-b} \tag{14.5}$$

In Eq. (14.5), $C'(1)$ does not incorporate the knowledge decay effect. However, (14.5) can fall back into the usual form (14.3) if one only considers the value $C(1)$ to be estimated from empirical data to include knowledge decay too, as in (14.6)

$$C(1) = C'(1)\delta^{-b} \tag{14.6}$$

Once parameters have been estimated—or drawn by analogy from similar products the firm has worked on in the past—learning curves can be used to forecast future cost. Using the Mean Value Theorem, and approximating the numbering of part 1 as part 0, one can derive the average cost of parts 1 through $n$

$$\begin{aligned} \overline{C}(n) &= \frac{1}{n}\int_0^n C(n')\mathrm{d}n' = \frac{1}{n}\int_0^n C(1)n'^{-b}\mathrm{d}n' \\ &= \frac{C(1)}{n}\frac{n^{1-b}}{1-b} = C(1)\frac{n^{-b}}{1-b} = \frac{C(n)}{1-b} \end{aligned} \tag{14.7}$$

Similarly, if one has to foresee the average cost of a batch of products ranging from part $n_1$ to part $n_2$,

$$\begin{aligned}\overline{C}(n_1, n_2) &= \frac{1}{n_2 - n_1}\int_{n_1}^{n_2} C(n)\mathrm{d}n \\ &= \frac{1}{n_2 - n_1}\int_{n_1}^{n_2} C(1)n^{-b}\mathrm{d}n = \frac{C(1)}{n_2 - n_1}\frac{n_2^{1-b} - n_1^{1-b}}{1-b}\end{aligned} \tag{14.8}$$

Equation (14.8), if coupled to a forecast of production volume over time, can be very useful to foresee the average production cost in the time period that will see the production of parts $n_1$ to $n_2$.

An interesting property of the Crawford–Boeing model is that, at each doubling of production (e.g., when going from the 2nd to the 4th part, or from the 120,000th to the 240,000th) production cost will be reduced by the same relative amount 1-$\alpha$. In fact,

$$\frac{C(2n)}{C(n)} = \frac{C(1)(2n)^{-b}}{C(1)(n)^{-b}} = 2^{-b} = \alpha, \tag{14.9}$$

$$b = -\frac{\ln \alpha}{\ln 2} \tag{14.10}$$

Therefore, an alternative way to defining the learning rate $b$ is through the cost reduction at each doubling of production, $\alpha$.

In order to understand the Crawford–Boeing learning phenomenon in greater depth, one may take Eq. (14.3) and at first take its derivative with respect to $n$

$$\frac{\mathrm{d}C(n)}{\mathrm{d}n} = \frac{\mathrm{d}C(1)n^{-b}}{\mathrm{d}n} = -bC(1)n^{-b-1} = -\frac{b}{n}C(n) \tag{14.11}$$

Equation (14.11) is the instantaneous *absolute* cost decrease at each increase of n. Then, the instantaneous *relative* cost decrease at each increase of $n$ can be found by dividing (14.11) by $C(n)$, yielding

$$\frac{\mathrm{d}C(n)/\mathrm{d}n}{C(n)} = -\frac{b}{n} \tag{14.12}$$

This can be compared to the behavior of the exponential learning curve, which is quite often used by psychologists and in the social sciences (Bills 1934; Teplitz 1991; Ritter and Schooler 2001):

$$C(n) = C(1)e^{-bn} \tag{14.13}$$

and

$$\frac{\mathrm{d}C(n)}{\mathrm{d}n} = \frac{\mathrm{d}C(1)e^{-bn}}{\mathrm{d}n} = -bC(1)e^{-bn} = -\mathrm{b}\ C(n) \tag{14.14}$$

and hence:

$$\frac{\mathrm{d}C(n)/\mathrm{d}n}{C(n)} = -\mathrm{b} \tag{14.15}$$

If a learning phenomenon follows the exponential learning curve, the relative cost decrease remains constant with $n$. This is equivalent to stating that—if learning has to do with identifying and solving areas of improvement (or inefficiencies)—the slope of $C(n)$ will decrease simply because the number of residual inefficiencies becomes progressively lower. Instead, in the Crawford–Boeing model, the relative cost decrease shrinks hyperbolically with $n$. This is like saying that residual inefficiencies to be tackled are progressively not only fewer, but also either harder to spot or to solve.[23] Students of learning phenomena (Dar-El 2000; Liao 1988) tell us that, while the exponential model holds well when learning occurs at individual or small-group level, the Crawford–Boeing model is better at representing learning phenomena at organizational level. It is not surprising to see that learning at organizational level is more complex and difficult to pursue than for individuals.

These considerations have interesting practical implications. For instance, firms who launch cost reduction programs in order to improve their competitiveness often set targets such as "*we will reduce cost by x % per quarter over the next two years*", and will tend to do so during a time of crisis. This approach is inherently flawed because of two reasons. First, it is not time, but volume that can drive a decline in costs (so, ambitious objectives are easier to meet when demand is going well than when it is shrinking). Second, even if demand and time were proportional, organizational learning would usually not lead to a constant relative change in cost. Therefore, achieving a constant relative cost reduction per time unit when demand is decreasing is impossible, if not accepting to degrade product quality.

### 14.5.4 Life-Cycle Costing

Traditionally, product costing had to do with computing the costs that were associated to the manufacturer, be they fixed or variable, direct or indirect. However, products usually determine numerous other costs during their operation, servicing, and at the end of their lives. If one thinks of a passenger car, the money spent in

[23]When dealing with continuous improvement projects, it is customary to say that it is easy to "*pick low-hanging fruit*" at first. Following on this analogy, exponential learning would be as if fruit had already fallen on the ground, and one simply had to find it hidden in the grass.

fuel, repairs, insurance, and toll roads is likely to be of the same order of magnitude than the money spent to buy the car. Energy-intensive appliances (e.g., light bulbs, electric heaters and air conditioners), or durable goods used by businesses, such as commercial planes and trucks, easily have an acquisition cost that is only a small share of the overall costs associated to the product throughout its lifetime.

As it has been discussed in previous chapters, the majority of these costs are determined by design decisions made during the early stages of the development process (Ulrich and Eppinger 1995). In the past, designers would have aimed at complying with target manufacturing costs, somewhat leaving the other lifecycle costs as a relatively uncontrolled consequence of their decisions. This approach is nowadays seen as too myopic, since the lifecycle consequences of design decisions can have significant impact on product success. Conversely, taking them into account in order to reduce the overall lifecycle cost ("*designing for cost*" in the words of Dean and Unal 1992) can have significant strategic value for the firm. For instance, a decision that leads to reduced manufacturing costs may make field service extremely difficult and expensive, thus reducing the attractiveness of the product. Conversely, a design with higher manufacturing cost that must be sold at a higher price might be attractive, provided it requires significantly lower operation, maintenance and disposal costs[24] (Dunk 2004). In order to work properly, this tradeoff mechanism must be objectively advantageous, easy to communicate, and requires customers willing to accept making the investment. In some cases, benefits and tradeoffs must be played out by involving multiple parties, or stakeholders. For instance, if a carmaker wants to incorporate features leading to a reduced pedestrian impact in case of accident, the added cost will be easier to justify if insurance companies are ready to decrease the insurance premium.

From a strategic perspective, taking a broad perspective on life-cycle cost allows firms to innovate their business models. For instance, a manufacturer may decide to shift from the simple production of goods to the provision of services, in order to internalize different lifecycle phases and the profits accruing from a proper management of tradeoffs.[25] Similarly, producers can purposely shift their revenue streams and their profits from one lifecycle phase to the other, and decide to gain from the future use of their products, rather than from their initial adoption. In the so-called *razor and blades** business model, the firm sells the product at or below cost and then profits from sales of consumables (e.g., razor blades in the case of shaving razors, cartridges for inkjet printers, and coffee pods for espresso machines).

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[24]For instance, an automotive manufacturer that is developing a passenger car may decide to incorporate components that are more expensive but more reliable than the ones that were previously used, and therefore decrease servicing requirements for the vehicle.

[25]For example, if customers are unwilling to pay a higher price for a system that has very low maintenance costs, a producer might find it highly profitable to start leasing it. This is especially true if the producer is able to secure finance at low interest rates, while customers base their purchasing decisions on short-term criteria such as Payback Time.

Life-Cycle Costing, defined as the "*systematic analytical process of evaluating various designs or alternative courses of action in relation to their lifecycle impact*" (Fabrycky and Blanchard 1991) is a well-known approach for achieving the goal of "designing for cost". The Life-Cycle Cost (LCC) is defined as the overall cost associated to the product, from its inception to its withdrawal at the end of its life. The overall costs that are experienced by the customer are instead termed Total Cost of Ownership (TCO). Making a systematic assessment of LCC and TCO, is based on the following steps:

- The life-cycle costs associated to the product can be analyzed and arranged hierarchically in a Cost Breakdown Structure (or CBS). In general, the first level of the CBS distinguishes between R&D cost, manufacturing (or "investment") cost, and operations and maintenance cost (left-hand side of Fig. 14.13).
- Stakeholders that are involved in the product lifecycle are identified, and costs in the CBS can be allocated to stakeholders according to the current (or *as-is*) state (right-hand side of Fig. 14.13). When doing so, each element may be analyzed by looking at both the simple cost to the stakeholder who directly bears it, and by studying the economic exchanges that occur between stakeholders, including their margins.
- After performing a critical analysis of the *as-is* cost-stakeholder matrix, the firm can work on the new product at different levels, both tactical and strategic, and define a *to-be* matrix that will serve as a requirement for product design

Figure 14.14 reports a toy example related to a washing machine. Seven life-cycle phases have been considered, and five stakeholders have been identified. The matrix on the top reports the pure cost of each phase and its allocation to the stakeholders who directly bear it. The matrix on the bottom reports the overall economic flows between stakeholders, including their revenues (which will appear as a cost to some other stakeholder). For instance, the pure cost of distribution appears to be 80 € and is borne by the distributor. However, since the distributor

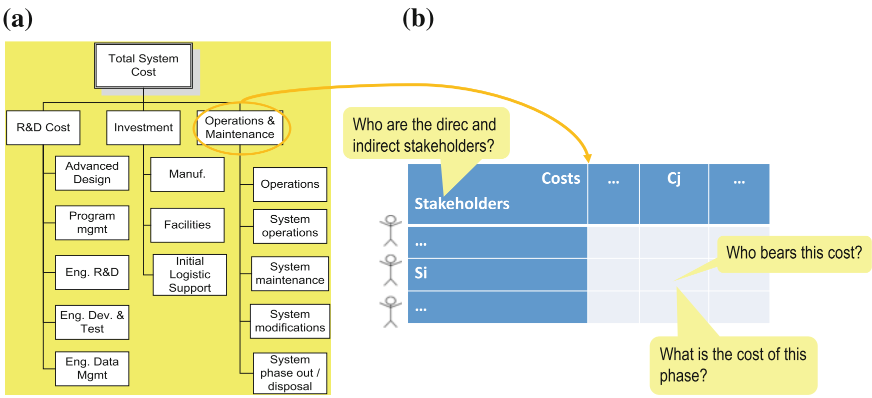


**Fig. 14.13** Cost breakdown structure and cost allocation to stakeholders in life-cycle costing

(a)

| Internal cost | | Production | Distribution | Installation | Operation | Consumables | Servicing | EOL | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Producer* | | 150 | | | | | | | **150** | **14%** |
| *Distributor* | | | 80 | 20 | | | | 100 | **200** | **19%** |
| *Maintenance* | | | | | | | 200 | | **200** | **19%** |
| *Consumables vendor* | | | | | | 400 | | | **400** | **38%** |
| *Customer* | | | | | 100 | | | | **100** | **10%** |
| **Total** | | **150** | **80** | **20** | **100** | **400** | **200** | **100** | **1050** | |
| | | **14%** | **8%** | **2%** | **10%** | **38%** | **19%** | **10%** | **100%** | |

(b)

| **Overall flows** | | Production | Distribution | Installation | Operation | Consumables | Servicing | EOL | **Total** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Producer* | *Revenue* | 200 | 0 | 0 | 0 | 0 | 0 | 0 | **200** | | |
| | *Cost* | 150 | 0 | 0 | 0 | 0 | 0 | 0 | **150** | | |
| | *Margin* | 50 | 0 | 0 | 0 | 0 | 0 | 0 | **50** | | **14%** |
| *Distributor* | *Revenue* | 0 | 380 | 0 | 0 | 0 | 0 | 40 | **420** | | |
| | *Cost* | 0 | 280 | 20 | 0 | 0 | 0 | 100 | **400** | | |
| | *Margin* | 0 | 100 | -20 | 0 | 0 | 0 | -60 | **20** | | **5%** |
| *Maintenance* | *Revenue* | 0 | 0 | 0 | 0 | 0 | 300 | 0 | **300** | | |
| | *Cost* | 0 | 0 | 0 | 0 | 0 | 200 | 0 | **200** | | |
| | *Margin* | 0 | 0 | 0 | 0 | 0 | 100 | 0 | **100** | | **27%** |
| *Consumables vendor* | *Revenue* | 0 | 0 | 0 | 0 | 600 | 0 | 0 | **600** | | |
| | *Cost* | 0 | 0 | 0 | 0 | 400 | 0 | 0 | **400** | | |
| | *Margin* | 0 | 0 | 0 | 0 | 200 | 0 | 0 | **200** | **370** | **54%** |
| *Customer* | *Revenue* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | | |
| | *Cost* | 0 | 380 | 0 | 100 | 600 | 300 | 40 | **1420** | | |
| | *Margin* | 0 | -380 | 0 | -100 | -600 | -300 | -40 | **-1420** | | |
| **Total** | ***Revenue*** | **200** | **380** | **0** | **0** | **600** | **300** | **40** | | | |
| | ***Cost*** | **150** | **80** | **20** | **100** | **400** | **200** | **100** | | | |
| | ***Margin*** | **50** | **300** | **-20** | **-100** | **200** | **100** | **-60** | | | |

**Fig. 14.14** A simple example for life-cycle costing analysis

also buys the washing machine from the producer at a price of 200 €, his total cost will be 280 €. Similarly, the distributor completely bears full the cost of installation (20 €) and 60 % of the 100 € cost of withdrawal of the product at the end of its life (the rest being paid for by the customer).

The matrix can be read by cost element (by columns) and by stakeholder (by rows). From the former perspective, it appears that the majority of costs and margins are associated to dealing with consumables. So, a producer may see the cost of consumables as an interesting area of improvement (e.g., developing a washing machine that requires less use of detergent) or even as a strategic direction in business model innovation (e.g., proposing a "full service" contract including the supply of detergent). Instead, by reading the matrix from a stakeholder perspective, one realizes that the distribution activity is only apparently profitable. The profits earned by distributors are in reality quite meager given that—in the current business model—this actor subsidizes both installation and decommissioning. The producer may therefore become much more attractive to distributors by introducing innovations aimed at reducing these costs.

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# Chapter 15
# Designing the Product

With this chapter, our journey in product development enters the design phase, a stage that requires us to adopt a deeper technical perspective. In Chap. 14, product specification was mainly concerned about what the product should be like, do, and perform. In this chapter, we will move on to discussing how technical solutions to these desiderata may actually be found. The discussion will start from the theoretical underpinnings of the design activity, and then present methods and tools that support designers' activity. The discussion will not enter the stages of embodiment and detailed design, which would require discussing discipline-specific (or industry-specific) methods and perspectives, which would lead us beyond the scope of this textbook.

## 15.1 Some Theoretical Foundations of Design

### *15.1.1 Design as the Cognitive Process of Technology*

From an engineer's perspective, *design** is a quintessentially technical activity, in which the designer puts technology to practical use, in order to achieve a desired result. However, if one focuses on the subject—rather than on the object—of the design activity, one quickly realizes that design is a very "human" activity that occurs in the brains of individuals and through social interaction. Therefore, it is quite apparent that design cannot be completely understood if one adopts a merely technological perspective. Instead, the comprehension of the design process requires adopting multiple "lenses", which may come from fields such as philosophy, cognitive and social sciences, etc.

To this purpose, one can even go back to Aristotle, when the ancient philosopher identified the dualism between science and technology, at the same time being one of the first to recognize design as a distinctively human and philosophically relevant activity. Elaborating on Aristotle's view, science and technology can be roughly classified as in the following Table 15.1.

The essence of design is *to devise a solution that will work in practice*. This implies creating an artifact that is able to perform as intended in a given situation,



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_15

**Table 15.1** The distinction between science and technology

| | Science | Technology |
|---|---|---|
| Purpose | Science (episteme) produces knowledge and theory (theoria) | Technology (techne) has the purpose of creating and creating (poiesis) |
| Cognitive approach | Science moves from specific facts to create generalized knowledge (inductive approach) | Technology moves from generalized knowledge to determine specific actions (deductive approach) |
| Reference frame | The scientist defines a "space of phenomena" and seeks rational explanation for them | The technologist generates a "solutions space" and seeks a suitable and workable one |

thus answering to specific goals and intentions. Conversely, a design that is generically applicable to a host of situations, but does not really perform adequately in any of them, would be of no real use. A good design would be able to tackle at least one given situation well, while an "ideal" design would perform successfully in a wide range of circumstances.

Another typical aspect of design is its creative nature, which further reinforces the previous statement that it must be studied in relation to its human origin. Creativity does not occur as a single event but—rather—as a complex cognitive process in which the designer must first of all frame and understand the problem (*problem formulation* or *problem setting*). Then, the designer will generate a space of potential solutions, which is the core creative phase, using a "divergent thinking" approach. Finally he will select and refine the solutions until a suitable one emerges. This requires making a synthesis through "convergent" thinking.

Especially in the early, creative and divergent parts of the design process, pre-defined strategies, methodologies and algorithms can provide guidance but—at least at the current state of the art—cannot deliver solutions autonomously. In the subsequent steps, the final and detailed solution may emerge through a more structured and somewhat easier-to-automate process.

### *15.1.2 Simon and the "Sciences of the Artificial"*

Moving fast forward, we can jump from Aristotle to Herbert Simon, an author that has made key contributions to the way with which we nowadays look at design. Simon was originally an organizational scientist and economist, who won the Nobel Prize for economics in 1978 thanks to his studies on the nature of human reasoning and decision making and—specifically—as a key contributor to the "theory of bounded rationality".[1] In the second part of his career, Simon decided to continue

[1]The theory of bounded rationality challenges traditional models in economics, in which human beings were represented as utility-maximizing and perfectly rational decision-makers who operate on perfect information. According to Simon, humans operate on imperfect information (since

working on decision making and human cognition with a broader perspective. In his landmark book "The Sciences of the Artificial" (1969) he advocated ending the dualism between science and technology by giving scientific relevance to the latter, and moving beyond the traditional representation of technology as a field based on empiricism and tacit knowledge. Simon justified this position because of both intellectual and practical reasons.

Concerning the former, he observed that the world we live in is mainly shaped by humankind's design activity. Therefore, while scientists have traditionally dedicated most of their efforts to studying the natural world, it should make as much sense to research the artificial world and the way it evolves. Such a research should be carried out by using a scientific approach, and should focus on design, which is the "phenomenon" that generates and progressively modifies this pervasively artificial world. Under this perspective, design is the human activity *par excellence*, since human beings spend most of their time "*designing courses of action*". Such a view of design is very broad indeed, since it encompasses a very wide spectrum of artifacts and not only ones having to do with technology, as is commonly understood. In fact, Simon has the merit of having been one of the first to identify the strong cognitive similarities between seemingly quite different creative activities, and having viewed design as their common trait. According to this view, the activity performed by a mechanical engineer involved in the design of a gearbox is not at all dissimilar from the one carried out by a manager who is designing a professional development path for the employees in her company, or by a group of friends who are planning their next holiday journey. A corollary to this viewpoint is that design cannot be understood from the perspective of a specific technology, and its deep comprehension requires investigating it as a *cognitive phenomenon*. As a further implication, the design activity must be seen as largely independent of technical domains and economic sectors.[2]

Moving to the practical reasons, Simon suggested that the scientific study of design would lead to desirable outcomes, such as the elevation of its social and intellectual status, and this would allow the attraction of talented individuals to the field. Moreover, a better understanding of the cognitive processes that occur within design could lead to the development of better and scientifically grounded methods and tools, which would improve the performance of design activity. In turn, this would have had a substantial and positive impact on the competitiveness of firms

(Footnote 1 continued)

information may not be available or may be costly to obtain) and do not have the ability or the time to act in a way that is perfectly rational and utility-maximizing. So, instead of making "optimal" decisions, they rather look for "satisficing" solutions, i.e., solutions that—given the information and the means available—will provide them with a utility that passes a given threshold and is therefore acceptable.

[2]This uprooting of design from its technical and industry-specific origins has not been easily accepted by those who have a "bottom-up" and strongly mono-disciplinary perspective. Curiously enough, this is more common in academic circles than in industry, where the interdisciplinary nature of design activities is ever more seen as a fact and as a challenge to be embraced.

and on the economy in general. The focus on design as a cognitive phenomenon led Simon to viewing the then emerging field of Artificial Intelligence as his main area of interest. In hindsight, advances in the field did lead to the development of many powerful new methods and tools supporting design, but not (or at least not yet) to the fulfillment of Simon's original vision of "intelligent algorithms" enabling and automating design activity.

In Simon's wake, academic research on design has been carried out by many authors from different fields and pursuing quite a wide range of objectives. Following Cross' classification (2001), design research is a broad field of investigation that attempts to move beyond the traditional effort of "scientific design", which is the use of scientific concepts rooted in a given discipline in order to support design activities (e.g., using Ohm's law to design an electric circuit).

As represented in Fig. 15.1, design research can be classified as a "science of design" whenever design is viewed as a phenomenon to be studied scientifically. In this case, researchers view designers and the design process as objects of investigation, and try to understand how they work, assuming academic perspectives that can range from psychology to ethnography and from cognitive to organizational science. This type of research is generally carried out through experimental or empirical studies.

On the other side, design research can be viewed as "design science[3]", when it has the aim of developing scientifically based methods and tools to improve design action with a normative approach. What sets this apart from "scientific design" is that design science methods are generally domain-independent and derived from the outcomes of the "science of design", and not of natural sciences. As practical outcomes of design science, one can think of design methodologies that can be taught to novice designers in order to accelerate their professional development, the definition of methodological standards and norms defining the design process and its constitutive activities and, finally, the development of software tools supporting the design process at individual, group, or organizational level.

A complete survey of design research goes well beyond the objectives of this textbook, and for this purpose, readers may be referred to excellent surveys such as Bayazit (2004), Clarkson and Eckert (2005), Finger and Dixon (1989), Mehalik and Schunn (2006), Birkhofer (2011), Finke et al. (1992). Moreover, interested readers may find it fruitful to connect literature on design research to literature on problem solving in general (Eide et al. 2002; Sanabria and Orozco Pulido 2009; Liedtka et al. 2013). The following subsections will therefore provide just a few key findings that can be considered to be of greater significance for teaching purposes. Perspectives coming from the "science of design" will be proposed at first, and will be followed by a discussion on normative approaches to design.

[3]This objective of "design science" can be viewed in analogy to the one of "management science", which is usually defined as the application of scientific insight to improve managerial action.

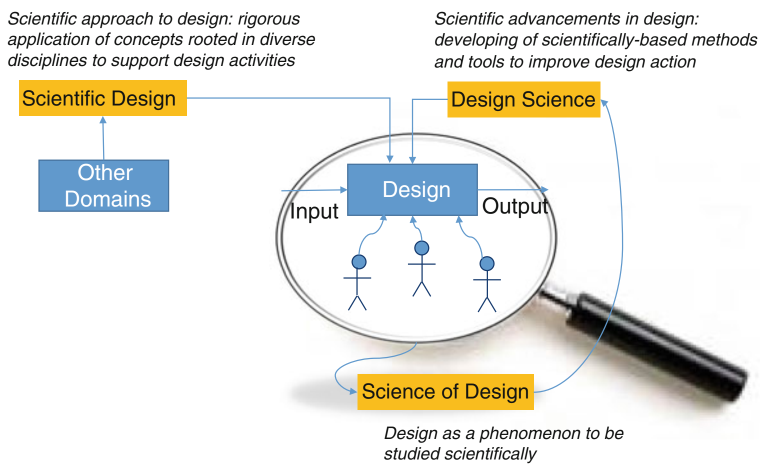


**Fig. 15.1** The relationships between design and science according to Nigel Cross

## *15.1.3 Some Perspectives Coming from the "Science of Design"*

### 15.1.3.1 Descriptive Models of Design at the Individual Level

At individual level, a first and notable contribution comes from Donald Schön, who was already introduced in Chap. 11. By studying the unfolding of activities in a number of professions, among which design, Schön examined the way with which experts devise "courses of action" when engaged in problem solving. He realized that—exception made for very simple and highly routinary problems—this process cannot be viewed as a rational and predefined sequence of steps in which a subject (i.e., the professional) operates on an object (i.e., the problem) by drawing on the knowledge she possesses. Instead, the problem and the professional can be considered as a "universe" within which both co-evolve. In this joint evolution, both the solution process and the solution progressively and iteratively emerge out of a continuous "reflective conversation with the problem". By running protocol studies,[4] Schön (1983) was able to frame his theory as described in Fig. 15.2.

[4]A protocol study is an experiment aimed at measuring and validating a theoretical framework on cognitive processes at individual or group level. The subjects involved are assigned a problem to work on and are asked to "think aloud" and provide as much visual support to their actions as possible (i.e., by sketching). The session is recorded with audiovisual means and then transcribed, assigning each element in the process (e.g., fragment of conversation, a non-verbal act of communication, a sketch, etc.) to the categories that were defined by the framework. The study allows researchers to evaluate the degree with which the observed process "fits" in these categories and to perform quantitative analysis on them (e.g., the frequency with which one category occurs, the time spent on each category, transition probabilities from each pair of categories, etc.).

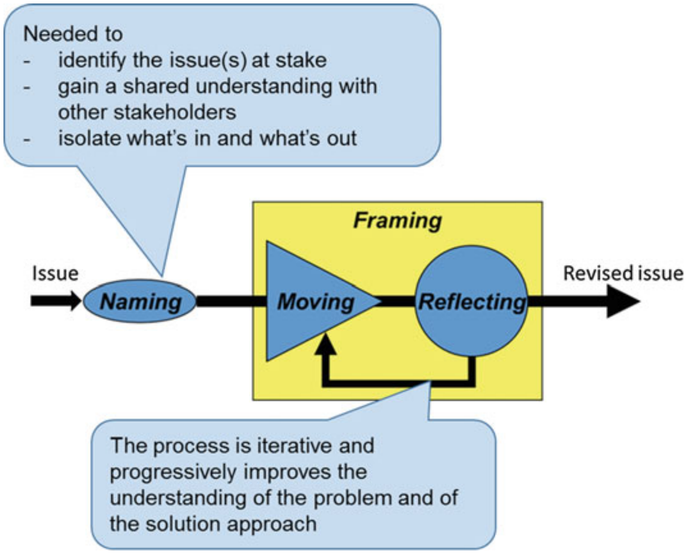


**Fig. 15.2** A simplified representation of design as "reflective practice"

The process starts with the "naming" of elements that are relevant to the problem. In this context, naming is not simply a matter of providing verbal labels to these elements, but also has to do with their identification. This also implies setting a boundary to the problem, thus excluding what can be considered to be irrelevant elements, and reaching a precise understanding of the ones to be considered, including the terminology with which they must be addressed.

Among the elements to be identified one can list *design parameters* (i.e., the elements that have to be decided on, such as "*what material should be chosen for part X*"), *specifications* (i.e., the functions or performance levels that have to be reached, such as "*the product must switch on in less than* 2 s") and *constraints* (i.e., the physical, organizational or legal elements that may influence decisions, such as "*we cannot require tighter tolerances than our manufacturing equipment allows*").

When design is carried out within a team that belongs to an organization and, even more, in the case of a team that spans multiple organizations, reaching an agreement on the elements to be dealt with and on the related terminology[5] is not trivial. However, the issue has significant implications for ensuring collaboration and for providing effective support by the means of information systems.

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[5]Anyone who has approached a sport such as mountaineering or sailing has experienced that technical terminology is quite complex, and also that one cannot become proficient without learning it. Similarly, anyone entering a professional domain is usually overwhelmed by the amount of technical jargon that is used. This vocabulary is often specific to individual firms and—if design has to be carried out in cooperation between different companies—it may also require some sort of translation.

**Table 15.2** The three types of reasoning used in design

| Type of reasoning | Structure | Example |
|---|---|---|
| Inductive | Facts → general statements and rules | "*Given lab results, component X fails at high temperature. Therefore, it should not be used above* 70 °C" |
| Deductive | General statements and rules → solutions | "*Given our design guidelines on component X at high temperature, and given that product Y is going to Africa where we foresee operating temperatures approaching* 80 °C, *we should therefore not use component X in product Y*" |
| Abductive | Experience → a plausible and economic justification (i.e., sufficient but not necessary) → solutions | "*Field failures of component X are occurring in hot climates. It is likely that X has issues at higher temperatures. Since product Y is being designed for Africa, we should therefore avoid using component X*" |

After naming, problems are "framed", i.e., broken down into elements and tackled frame by frame. Also in this case, the criterion with which a problem should be decomposed is not trivial and requires both experience and organizational-level agreement. Within each frame, the professional will act on the problem by alternating "moves" (i.e., making or suggesting decisions) and "reflections" (i.e., observing the impact of moves) until a satisfactory solution is identified, so that the process can shift to another frame. When designing, professionals usually engage in a variety of logical mechanisms. As noted by some scholars (Nakajima 1995; Zeng and Cheng 1991; Gero and Kannengiesser 2004), designers make use of multiple cognitive and logical approaches, as shown in Table 15.2. Specifically, designers do not only use traditional inductive and deductive reasoning, but also operate on an abductive approach, which allows to make an effective—though potentially imprecise—use of empirical observations.

Following Schön, the design process is strongly iterative and based on feedback loops that occur between the decisions taken and the analysis of their consequences. However, a designer does not simply "move around in circles" until a given condition is met. If one observes closely, the conclusion of each loop allows her to make steps forward, adding details at each step, which lead to an always crisper definition of the solution. From a high-level perspective, one can therefore see design as a process that is initially concerned with "task clarification" (i.e., understanding the problem and defining its boundaries and its objectives). Then, the process moves into a creative phase during which broad decisions are taken on the product and its architecture. Finally, the designer delves into "detailed design", in which he will define all the facets that are needed to provide a complete description of the previously identified solutions. By combining the two perspectives, iterative

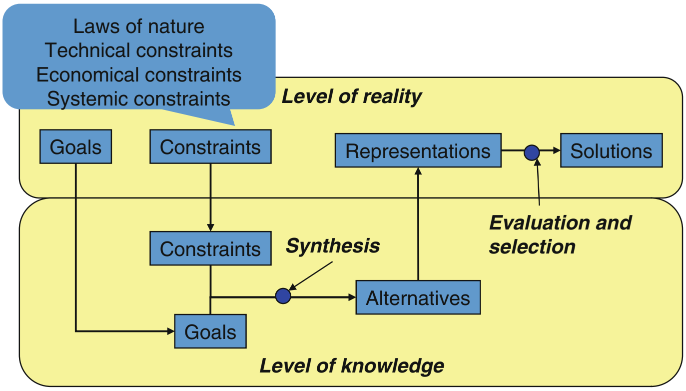


**Fig. 15.3** The design process iterates between the levels of reality and abstraction

and progressive, one can visualize the design process as a spiral-like process in which greater or lesser emphasis can be placed on one dimension or the other.[6]

A similar view of the design process has been formulated by Smith and Browne (1993), who concentrated on the cognitive effort made by designers in managing elements such as goals, constraints and solutions. According to these authors, and as described in Fig. 15.3, designers continuously alternate between the level of reality they are ultimately interested in (i.e., what is actually required, what is actually working, etc.) and the level of knowledge and abstraction in which they cognitively operate (i.e., what they think is required, their mental models of relevant constraints, working solutions, reasons why solutions failed, etc.). Following this model, it is apparent that design does not only rely on the capability of generating solutions to perceived problems, but also on the capability of properly operating a continual translation between the two levels of "reality" and "knowledge".

#### 15.1.3.2 The Role of Constraints

Throughout this discussion, it is apparent that constraints are quite pervasive in the design process. Constraints have an ambivalent role in design. When the design task is aimed at incremental innovation, constraints may be viewed as helpful elements that provide guidance and restrict the variety of admissible solutions to a manageable subset, thus speeding up the design process. Conversely, if one aims at introducing

[6]Design researchers are often engaged in significant controversy over the nature of the "progressive" component of the design process. Some simply view it simply as the emerging result of the iterative component. Others instead ascribe a "normative" meaning to it, implying that design "must" progress along the path from unstructured and broad-based decisions to the structured and detailed ones. In this latter case, the progressive path can be required and planned, while the iterative component will be viewed as "incidental" and as something to be avoided as far as possible.

radical innovation, constraints will become obstacles that must be somehow removed, either by changing them, or by finding solutions that "circumvent" them.

Constraints may be due to laws of nature, to the technical environment and state of the art that characterizes the firm or the industry, to the economic conditions cast by target costing analysis, and to systemic influences. This latter type of constraints comes from the hierarchic nature that is a distinguishing feature of all technical systems (Simon 1962). A system is usually made out of building blocks—or *subsystems*—that may be chosen, but may not always be designed from scratch (e.g., a microprocessor in an electronic product). In the same way, a system operates within a supra-system that is taken as a given and cannot be modified (e.g., a passenger car must run on the fuel that the local transportation infrastructure makes available). Hardly any of these systemic constraints are "objectively" so. In fact—and as commonly found in many cases of decision-making—constraints simply are elements that one has "decided not to decide upon", or not to challenge. For instance, abiding to a local regulation is mandatory, but only given that the firm has decided to sell the product in that specific country without lobbying for a change in regulations. Similarly, constraints due to the technical infrastructure within the company, or arising from subsystems and/or supra-systems are effective only as long as the company has decided to keep them as "givens" and not to make any effort to change them. Even laws of nature may be "suspended", if the designer tries to devise modes of operation in which they reduce their impact (e.g., evaporation is due to a law of nature, but can be decreased by increasing ambient pressure). Following this line of thought, the more a designer accepts systemic constraints as givens, the lesser will be the scope for innovation. Conversely, broader and more radical innovations will occur when the designer attempts—and is given the freedom—to "change the givens" and challenge commonly accepted constraints.

#### 15.1.3.3 Descriptive Models of Design in Groups and Organizations

If one moves from the individual to the organizational level, an interesting contribution comes from the field of ethnography. When studying design as a social process, ethnographers (Bucciarelli 1988) have mainly focused on the symmetry that arises between the structure of the artifact (i.e., product architecture) and that of the organization that carries out the design. The reader should remember that this observation has already been made in Chap. 3, when dealing with architectural innovation. Ethnographers also observe that—especially when working on complex products—the designing organization becomes larger and involves numerous specializations, each of which will have its own specific way of modeling the product and its behavior (or "object world") and will use its own specific language to represent it.[7] When managing the design process and when trying to support the

[7]For instance, when working on a car body, an expert in aerodynamics will mostly think about the way with which surfaces impact on the flow of air, while a manufacturing engineer will

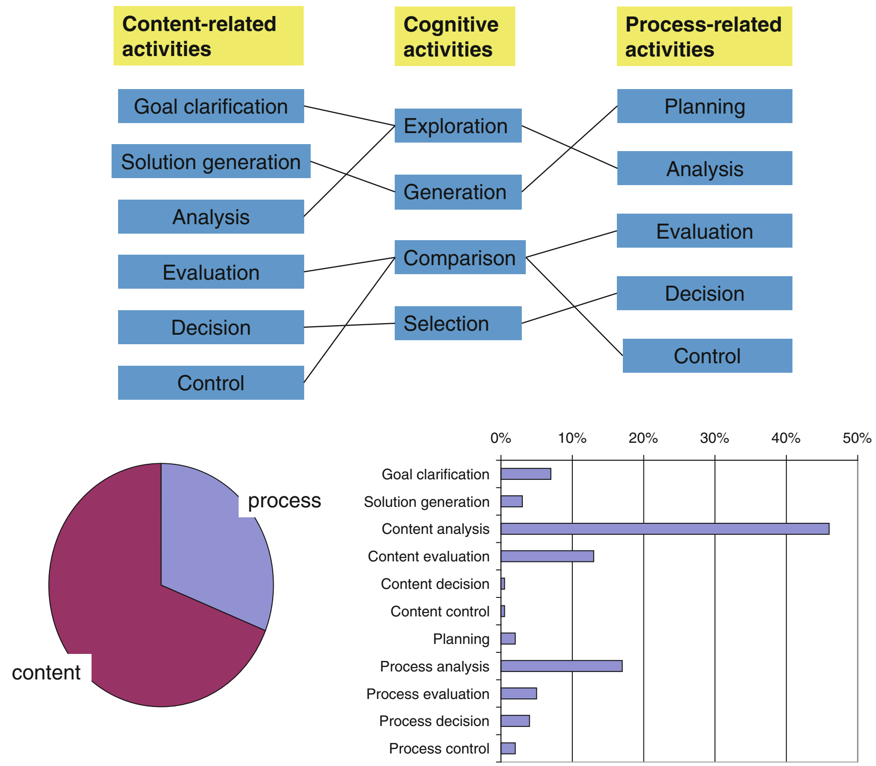


**Fig. 15.4** The share of time spent by design teams in different activities, following Stempfle and Badke-Schaub (2002)

related communication flows, a major challenge will therefore consist in reconciling these different object worlds and languages, so that different "engineering subcultures" may effectively work together.

Organizational psychologists have also carried out numerous studies of the design process at both individual and organizational levels. Among them it is worthwhile to mention Stempfle and Badke-Schaub (2002), who studied design processes in group settings with the aim of uncovering the main cognitive activities involved. At first they noticed—coherently with Schön's perspective—that these cognitive activities can be both content-related and process-related. The former have to do with the artifact, while the latter cope with the design process itself.

(Footnote 7 continued)

concentrate on the geometrical features and their radiuses of curvature, trying to figure out whether the metal can be deformed without excessive strain. The technical "languages" used to model product behavior and represent these thoughts will be quite different from one another and not be easily understood across disciplines.

Then, they further detailed such activities in subcategories (top panel of Fig. 15.4), and performed group-level protocol studies with the objective of measuring the time spent on each (bottom panel of Fig. 15.4).

The first element that emerges is the effort spent on process-related activities, which amounts to a quite substantial 1/3 of overall time. This finding supports the hypothesis we have now and again repeated, that the design process is not a predefined sequence of steps that can simply be followed as a given recipe. Another key finding is that design teams spend most of their time analyzing the ideas and proposals they have come up with. This is a further evidence of the explorative nature of the design process, in which iterations are central in defining and exploring the solution space. Finally, the percentage of time spent on solution generation (i.e., what is usually considered to be the core and "creative" part of design) is less than 5 % of the total. These results may lend themselves to two opposite interpretations. One interpretation accepts the complexity of the design process and the central role carried out by iterations, and considers them to be inherent properties of the design activity. On the opposite, one may conclude that the design process is—as of today—carried out in an extremely inefficient way, with close to 95 % of the time being spent in activities that do not directly "add value". Following this latter perspective, activities other than "solution generation" are necessary only because we have not yet been able to develop any other better and more efficient way to carry out the design process. Even though this perspective is quite extreme, it is impossible to challenge the idea that a method or tool able to streamline the analysis phases and to provide a focused direction to designers' "reflective conversations" would make the design process much more effective and efficient.

### *15.1.4 Normative Models from "Design Science"*

The previous discussion has been based on reviewing a few notable investigations that have focused on the question "what *is* design?" Now, this subsection will attempt to provide some key tools related to the "how *should* design be carried out?" question.

Most normative (or prescriptive) models are based on the key concepts of "function" and "form". The role of these two concepts can quite easily be understood if we look at the evolution that occurred in architecture and in industrial design during the early twentieth century.

Up to the nineteenth century, buildings were usually designed by focusing on formal stylistic elements that were typical of their time, geographic location and local culture, while their intended function was somewhat neglected. When visiting European cities one can notice that—probably with the exception of military architecture and churches—buildings of a given epoch tended to look very similar to one another, regardless of their usage. With the twentieth century, functionalist architects, starting from Louis Sullivan, started positing that "*form [ever] follows*

**Fig. 15.5** The Guggenheim Museum in New York as an example of functionalist design

*function*" (Sullivan 1896), i.e., that the geometry of the building should be designed with the aim of supporting the intended purpose of the building itself. In Le Corbusier's words, "*a house is a machine for living*". As an example of this way of thinking, one can consider Frank Lloyd Wright's Guggenheim Museum in New York (Fig. 15.5). In this well-known building, the architect had to reconcile the function of allowing effective visits to museum exhibits (which would call for a circular path without diversions into halls) with the constraints due to the limited space available, and came out with the helical structure that has become one of Manhattan's key landmarks. The theorization of the function-form dualism gradually spread from architecture to industrial design thanks to the work of functionalist architects who were also active in this field, such as Le Corbusier in France and Walter Gropius in Germany, who founded the Bauhaus movement.

From here, students of engineering design (Kesselring, Tschochner Niemann, Matousek, Leyer as cited in Pahl et al. 1988) started applying the same concepts to the design of technical systems and machines[8] in general. Following Rodenacker (1971) and Pahl et al. (1988), an artifact can be viewed (Fig. 15.6a) as a set of *functions* to be performed, as a physical *working principle* (or *process*) capable of fulfilling them, and as a detailed *form* implementing the working principle.[9]

Nearly all contributions to design science follow the idea that a technical system (TS) can be viewed under the triad defined by function, working principle and form, though the exact definitions may at times vary between authors (e.g., the Function-Behavior-Structure ontology proposed by Gero 1990). If one assumes a

[8]The term "machine" is here to be considered in its most general sense, i.e., as any artifact capable of transforming inputs into outputs, based on controls. Machines are therefore not only mechanical devices, but also electrical, electronic, or computational.

[9]For instance, a hammer has the function of "driving a nail in a solid body". The physical process used to fulfill this function is to "supply a few intense impacts by using the momentum created by a mass that is fixed at the end of a handle to which a small rotation is imparted". Finally, the hammer's form is the description of its components, geometry, masses, materials, etc. One should be aware that this is by no means the only process capable of driving a nail into wood, since this could also be accomplished by using multiple small impacts, by supplying a continuous pressure, and so on.

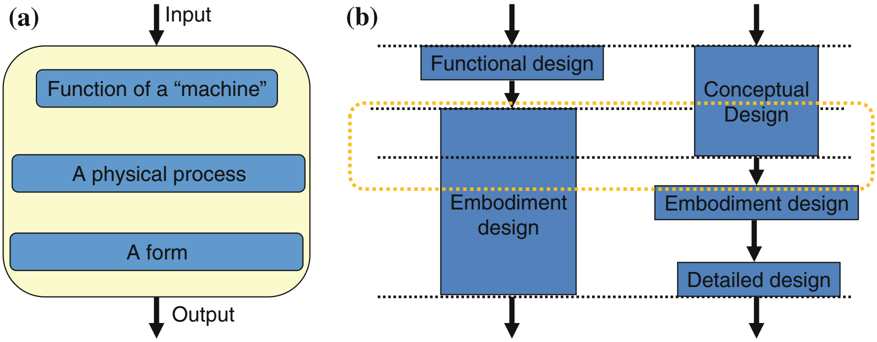


**Fig. 15.6** The design of technical systems following Pahl et al. (1988)

normative perspective, these three elements lead to designating the phases of the design process, since the designer must first of all define the artifact’s function, then choose a suitable working principle able to fulfill it, and finally proceed to describe the artifact’s form in detail.

One possible subdivision of the design process (Fig. 15.6b) splits the design process in the two phases of functional design (in which the designer concentrates on the artifact’s functions) and embodiment design (in which the designer picks a working principle and then determines form). This subdivision is seldom used, though it has the merit of making a clear separation between the space of functions and the space of physical embodiments. Instead, it is quite common to segment the design process in the following three phases as suggested by Pahl et al.:

- At first, the identification of functions and the choice of a process are performed together in the *conceptual design* phase. Conceptual design involves drafting functional descriptions, drawings and block diagrams, defining high-level lists of components and modules, and comparing and selecting alternative solutions.
- Conceptual design is followed by *embodiment design*, in which the product’s Bill of Materials (BoM) is defined in greater detail. Components are defined at the level of preliminary technical drawings, while a preliminary selection is made for their materials and manufacturing processes.
- Finally, *detailed design* copes with the dimensioning of the previous results, technical validation through extensive engineering calculations, and the detailing of all of the information that will be required to actually make the product.

These three design phases are substantially different from one another. For instance, creativity has a central role in conceptual design but hardly any role in detailed design. Moreover, information being produced and exchanged during the conceptual design process is relatively little and mostly unstructured, being limited to high-level descriptions of the product. During the embodiment design phase, the amount of information increases substantially and becomes somewhat more structured, with a focus on the architectural composition of the product. Finally, the detailed design phase witnesses a true explosion in the amount of information being generated and exchanged, involving the description of the most minute and detailed elements of the product and of its behavior.

These differences have a clear impact when one thinks of IT support to the design process, which must progressively shift from flexible tools aimed at supporting cooperative work to structured tools that focus on representing product BoM and, finally, to the provision of a complete product modeling system.

The three phases outlined above are always present in any design process. However, the weight and the effort cast on each will greatly depend on the innovative content that the design team has been asked to introduce. In the case of significant innovations (i.e., radical and/or architectural), conceptual design will have a major role, since the designers will be asked to conceive completely new technical solutions. In the case of modular or incremental innovations, conceptual design will have a passing role or be restricted to a few subsystems. In fact, a complete conceptual redesign of the product might lead to architectural change that would fall outside the scope of the design task that has been set up, or would challenge a dominant design that the firm does not wish to modify.

The following section will focus on the conceptual design phase, and will lead to the discussion of a number of general-purpose and domain-independent methods that have been devised in order to support it. As already stated, given the generalist nature of this textbook, and the fact that both embodiment design and detailed design are quite domain-specific, we will not discuss these two latter phases.

### *15.1.5 Methods Supporting Conceptual Design*

Following Ulrich and Eppinger (1995), it is possible to describe conceptual design as in the following Fig. 15.7a. At first, the design team formulates the design

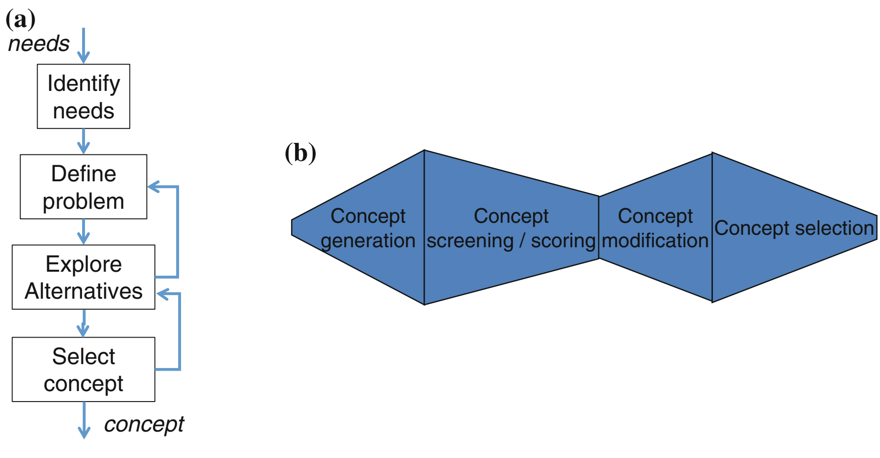


**Fig. 15.7** The conceptual design process

problem, identifying the functional elements that must be designed. The design process then enters its most creative phase, in which alternative solutions are explored and generated. This usually consists in the identification of a number of technical solutions, each of which can—at least in principle—fulfill the required functions. At this point, following Pugh (1981), each feasible combination of technical solutions makes up what is called a *concept*. Alternative concepts are then compared, so that the less promising ones are discarded, and the most promising ones are subject to further analysis and improvements. Finally, the candidate concepts are subject to a rigorous comparison and selection exercise, so that a single one may be chosen for further development during the subsequent embodiment design phase.

As shown in Fig. 15.7b, the conceptual design process alternates between divergent and convergent phases that are, respectively, characterized by relatively unbridled creativity and rigorous analysis. In general, a key rule to be observed in the conceptual design phase is that designers must come out with and work on multiple concepts. This is because only rarely will the "best" concept emerge at once, especially if the design team is trying to introduce a significant degree of innovation. On the opposite, it is quite likely that the first concept to emerge will just be a slight modification to currently prevailing technical solutions. The degree with which the divergent and convergent phases will be allowed to challenge the current state of the art will depend on the brief that has been assigned to the design team. In the case of radical innovations, the process might be allowed to proceed quite unbounded and possibly be iterated more than once. Conversely, in the case of incremental change, the process might be governed tightly, and allowed to introduce modifications only in the subsystems that have been identified as the most critical and in need of innovation.

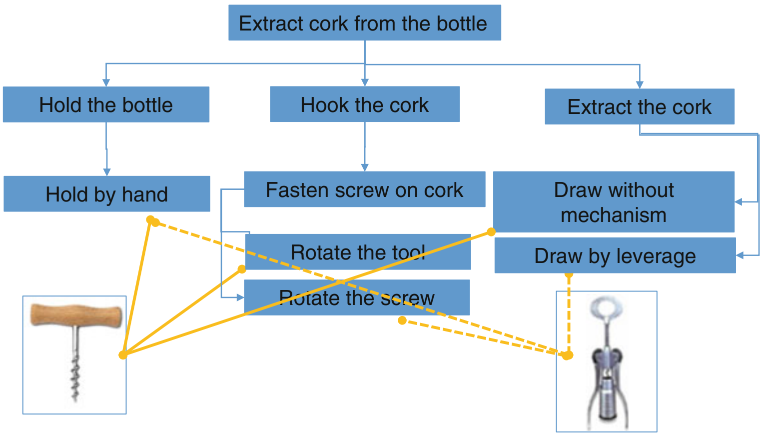


**Fig. 15.8** An example of function tree analysis

#### 15.1.5.1 Functional Analysis

As it has been mentioned, the first step in conceptual design lies in functional analysis. Defining the required functions of a product can generally be done by working with *function trees** or with *block diagrams**.

Function trees (Fig. 15.8) are based on the idea that a product can be described as a hierarchy of functions, starting from the root function that describes the core purpose of the product, and progressively detailing each function by exploding it into sub-functions. When exploding the function tree, sub-functions can be viewed as the answer to the question "*how can you?*" Conversely, when backtracking toward the root function, the aggregation of sub-functions is the answer to the question "*why do you*?"

Defining functions is not a trivial task, and requires a significant effort in providing precise verbal definitions, which ought to be expressed as a verb accompanied by complements. For instance, the core function of a corkscrew driver can be defined as "*extract + cork + from bottle*", which can be exploded according to the function tree in Fig. 15.8. As shown in the figure, at some point in the function tree, the designer may suggest alternative ways for fulfilling a higher-level function. This can be expressed in the function tree hierarchy by placing the functions on top of each other, instead of across. The combination of alternative working principles will ultimately lead to alternative concepts, as shown by the two different corkscrew designs depicted in the figure.

When one progressively explodes the function hierarchy, there may be a point at which the "*how can you?*" question is no longer answered by other lower-level functions, but by the description of physical processes or components able to fulfill or "embody" the functions (Fig. 15.9). The question therefore becomes "*what can you use to?*" Functional analysis is now completed, and the concept is defined by matching the function tree with the components list.

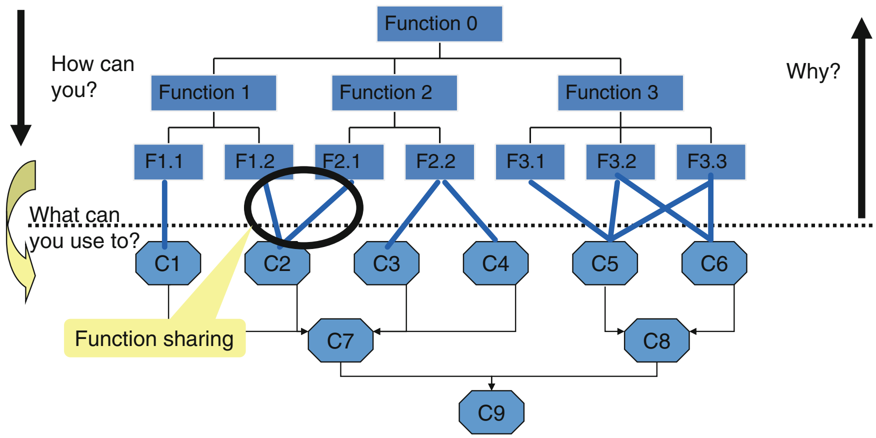


**Fig. 15.9** Defining a concept by matching a function tree with the embodying components list

Having identified the components list, it is customary to aggregate the components into a hierarchy, thus completing the definition of the product's BoM*. This aggregation can follow different criteria. For instance, one may generate an engineering BoM that replicates the structure of the function tree, so that "functional modules" may be mapped to higher-level functions. Another way to generate the engineering BoM would be to aggregate components by technical discipline (e.g., by aggregating mechanical, electrical and computational devices). A production BoM will instead combine components by considering the way with which they will be assembled. Finally, a purchasing BoM may be generated by clustering components by supplier, or by vendor type. Each of these BoMs is justifiable from an operational and logical perspective. The firm will therefore have to make sure that its information systems are able to manage multiple views of the same BoM and to guarantee its consistency, so that changes made (or required) by one view are correctly translated into the other ones.

Figure 15.9 shows that, when analyzing a product concept, the link between lower-level functions and components can exhibit different cardinalities.

- In the case of a 1:1 association there is a clear identification of which component fulfills which function, and vice versa. As we will see in Chap. 16, this functional separation between components leads to *modular* architectures. This significantly facilitates detailed design activities, and the use of standard and off-the-shelf components. For instance, a modification to the performance required of function F1.1 will require changing component C1, but it is unlikely that this change will propagate and require any redesign of other components.
- In the case of an *m*:1 association, a single component is able to fulfill m functions at the same time, and independently from other components. This is called *function sharing* (Ulrich and Seering 1988). In general, this choice leads to greater complexity in the detailed design phase and the use of ad hoc components. However, a single component able to fulfill more than one function can often lead to substantial savings concerning cost, weight, etc.
- With 1:*n* associations, a single function is fulfilled jointly by n components who do not serve other functions. This can be viewed as a shorthand representation of multiple 1:1 associations, since it is likely that the function could have been exploded into *n* sub-functions, each leading to a 1:1 association with the corresponding components.
- Finally, the case of an *m*:*n* association exhibits an arrangement in which components are functionally interdependent. As it will be seen in Chap. 16, this leads to an *integral architecture* in which detailed design becomes somewhat involved. In fact, any change carried out on one function or component will propagate to the other ones, thus triggering a chain of design iterations that will end only when a solution that satisfies the requirements cast by each function is found. Managing the detailed design process for products characterized by this type of architecture requires significant experience and—to this purpose—specific techniques have been developed (a review is given in Wynn and Clarkson

2005; while an in-depth analysis of the "signposting method" is provided by Clarkson and Hamilton 2000).

When going through the previous discussion, the attentive reader may have noticed a potential ambiguity. Functional analysis should operate in a way that is neutral with respect to potential embodiments, at least until one reaches the level of components. However, in Fig. 15.8, the "securing the cork" function is achieved by "inserting screw in cork", which implies that there will be a screw in the components list. This is not a mistake, since functional analysis is an integral part of the design process and can involve design choices of a functional nature, which may of course hint towards specific embodiments. However, the designer must be aware that the term "screw" being in used in the functional context is not to be seen as a component yet, but as a working principle.[10] Taken to the extreme, even the definition of the root function is the outcome of a design choice and depends on the innovative content that one wishes to introduce in the process. In fact, "extracting a cork from the bottle" is not the only way to allow the spillage of its contents, that is the final outcome being sought when using a corkscrew. Alternative—though probably not as practical—ways to achieve this same result would be the puncturing of the cork, its dissolution with an acid, or the clear cutting of the bottle at its neck (as, for instance, is done with drugs in ampoules, or when opening a champagne bottle with a sabre).

Functional analysis can also be carried out with function diagrams. For instance, Function Analysis System Technique (FAST) diagrams follow the blueprint shown in Fig. 15.10, in which the product's functions are described by showing how a set of inputs is progressively transformed in a set of outputs by a network of functional elements. With respect to function trees, a FAST diagram does not make the functional hierarchy explicit, but it provides much greater insight on the way with which the artifact works and on how its elements interoperate.

In its standard layout, a FAST diagram requires the definition of system boundaries, while the transformation of inputs into outputs proceeds from left to right. Furthermore, a distinction is made between primary (or core) and secondary (or auxiliary) functional elements. The former are directly involved in the conversion flow of inputs into outputs. The latter are instead required only to enable the operation of primary functional elements. For instance, a projector may have a primary "*provide light*" functional element, which will usually be embodied by a halogen lamp. The projector will also have a secondary "*generate flow of air*" functional element (probably embodied by a fan) that enables the operation of the "*provide light*" element.

[10]In this example, "screw" is to be intended as shorthand for a "helical inclined plane that enables the easy insertion of an element of the corkscrew driver inside the cork, in such a way that it will lead to a solid connection between the two, enabling future extraction by traction". An alternative —though quite fanciful—way to achieve the same result of "securing the cork" would be to "connect with adhesives", where the focus would be on the principle of adhesion, rather than on the adhesive that will be used.

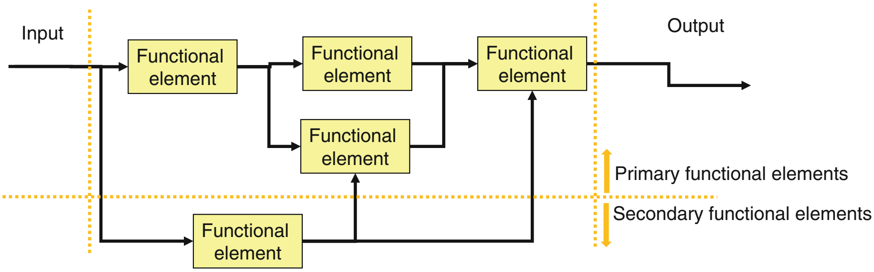


**Fig. 15.10** A FAST diagram

A FAST diagram is not simply a block diagram. In fact, its building blocks are not components but functional elements, though of course they will be embodied by physical components and subsystems in the subsequent phases of the design process. Just as in the case of function trees, there will always be a latent ambiguity between the "purity" of the functions that are being represented and their implied embodiments. Looking back at the previous example, the "*generate flow of air*" functional element has a role only if the embodiment of the "*provide light*" functional element is known to generate a significant amount of unwanted heat. In the case of fan-less projectors using low-power LED light sources, the "*generate flow of air*" functional element might either disappear, or be substituted by an "*allow flow of air*" element (that will be embodied by simple vents in the casing).

Functional diagrams can be developed in a variety of ways. It is worth mentioning Rodenacker diagrams (Fig. 15.11) in which relationships and flows between functional elements are graphically coded depending on their nature. In a Rodenacker diagram the designer must distinguish among material flows, energy flows and information and control flows. An additional relationship can be coded in the form of spatial constraints dictating either physical adjacency or separation between two functional elements. For instance, the battery of a car and high energy-consuming apparatus, such as the starter motor, might be constrained to be

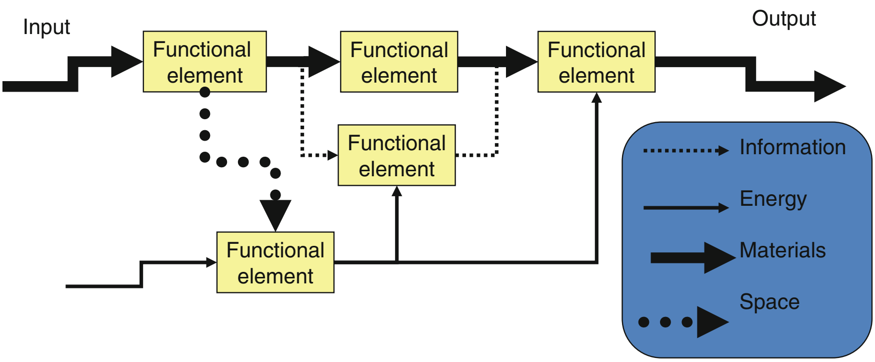


**Fig. 15.11** A Rodenacker diagram

located close to one another in order to reduce energy losses and/or minimize the amount of high-diameter wiring connecting the two. Conversely, the car engine and an accelerometer may be constrained to be set physically apart, in order to decrease the disturbance generated by the former's vibrations on the latter.

#### 15.1.5.2 The Creative Generation of Functional Embodiments

The creative core of conceptual design lies at the interface between the exploration of the function space and the definition of embodying components. This is a critical area of design, since it determines most of the future performance of the product and represents the area in which innovative content may be introduced. Moreover, the definition of functional embodiments defines product architecture and—as we well know from previous chapters—product architecture will henceforth tend to "lock-in" and lead to significant inertia. When defining product concepts, a tradeoff will have to be struck between creativity and conservation of previous designs, in a way that is coherent with the brief given to designers at the beginning of the process.

As mentioned earlier, conceptual design will usually alternate divergent and creative phases with convergent phases, with the latter being aimed at analyzing and selecting solutions. The creative generation of solutions can be seen as the outcome of the following process (Fig. 15.12, adapted from Ulrich and Eppinger 1995).

At first, and based on the outcomes of functional analysis, the design team will identify the key subsystems to work on. At this point, the team may start working both individually and as a group in order to come out with technical solutions. Though this phase is often seen as a task to be carried out as a team, it is imperative that individuals come to the group session after having performed some preliminary

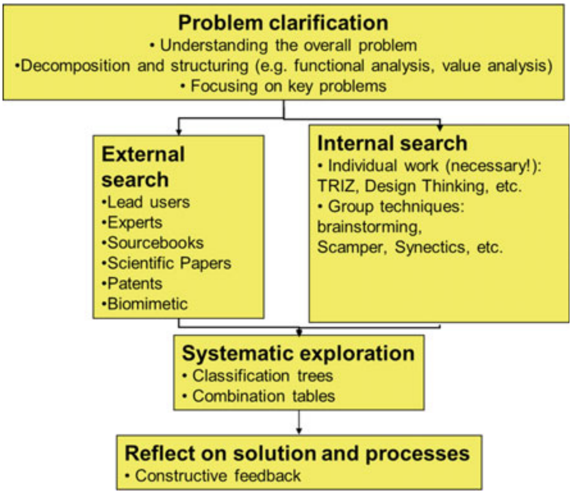


**Fig. 15.12** The concept generation process

research on their own, so that they can provide a richer and broader contribution. The individual search for solutions can be carried out by using a number of possible sources, such as:

- Interviewing **lead users** in order to gain insight on solutions they may have generated. Lead users (Von Hippel 1986) are users of a product or service who—because of their intense exposure to the product and capability to modify it—are likely to have come out with creative solutions to problems. Following Berthon et al. (2007) lead users are "*customers who adapt, modify, or transform a proprietary offering*".
- Interviewing **domain experts** such as suppliers and academics, who may have anticipated exposure to the emerging state of the art.
- Reading **technical and scientific literature**, in order to keep abreast of new solutions to technical problems that are arising in the industry.
- Domain-specific **sourcebooks**. Sourcebooks are repositories that classify problems that are typical of a given domain and provide a collection of known solution principles that a designer may choose from and adapt. For instance, a mechanical engineering sourcebook such as Artobolevsky (1975) may list dozens of ways to "*transform linear into circular motion*". Historical sources can also be helpful. Manuscripts by Renaissance inventors such as Leonardo da Vinci and Francesco di Giorgio Martini provide an impressive coverage of technical solutions that designers can still use for inspiration.
- **Product benchmarking** and **reverse engineering***. By looking at how competitors are dealing with technical problems, and studying the solutions they have come up with, usually provides valuable insight for conceptual design. In order to be proficient in this activity, the firm must set up a regular process for collecting competitors' products from the market, assessing their performance in a laboratory, and disassembling them in order to study the solutions being used. In some industries, this service may be provided by independent firms.
- **Patent search**. The widespread availability of full-text patent databases has become a very important resource for conceptual design. A patent database may be used in two ways. The first consists in observing the state of the art in the same industry, in a way that is quite close to reverse engineering competitors' products. However, compared to reverse engineering, patent search also allows looking into technical solutions that have not yet been launched on the market. Given the monopoly granting nature of patents, patent analysis also allows the firm to define its Freedom To Operate, i.e., to understand which solutions are legally pursuable and which are not.

  Patent analysis may also be used to look for solutions to analogous problems arising in other industries. For instance, a company that is working on pipeline inspection devices may be inspired by solutions developed for endoscopes used to inspect the human circulatory system. It is quite likely that the claims of these "analogous" patents will not be so extensive as to prevent the use of the same solution principle in a completely different application and industry. This being the case, the idea can be used without infringing the patent holder's rights.

Should the patent be very wide, the holder of the "analogous" patent might not be a competitor to the firm, and this makes it likely that it will be possible to negotiate a license.
- **Bio-inspired design*** (Goel et al. 2014; Macnab 2012) is another technique that uses analogies between problems, but looks for inspiration from nature. The power of biomimetics lies in the remarkable way with which evolutionary dynamics have progressively shaped living beings and allowed them to successfully adapt to the environment. Well-known examples of biomimetically inspired solutions are Velcro straps, which were conceived by observing at burdock burrs, and surface finishing that minimizes water drag, designed by emulating the structure of shark skin.

After having carried out this preliminary research, individuals may need to re-combine, re-think, and sediment ideas and intuitions. We all know from experience that this reflection usually requires some time, as well as events such as a night's sleep, a long flight, or a relaxing walk during the weekend. It is therefore advisable to leave a gap between the carrying out of individual work and the date when the group session for sharing ideas and generating new ones will be held.

A number of group-level creativity-fostering techniques have been proposed in the past, with the aim of stimulating people to think "out of the box" and concentrate on the generation of new ideas, deferring critical analysis and selection. The main techniques used in conceptual design are the following.

- **Brainstorming*** (Osborn 1953) is the most well-known creativity-fostering technique and—in its many variations—is amply used outside the design environment as well. Brainstorming requires participants to freely engage in the proposal of new ideas, with an explicit prohibition of making critical remarks on any. The aim is to collect a diverse group and generate as many ideas as possible with the involvement of all participants, trying to avoid social or hierarchical inhibition between people of different age or status. A brainstorming session usually requires a facilitator in charge of maintaining discipline, keeping up enthusiasm, and stimulating the association and combination of ideas into new ones. In general, brainstorming is supported by visual tools such as sticky notes to be placed on a board, ideas galleries to be shown to other people, magazines for clipping pictures that may be associated to the ideas, etc. The brainstorming session may be organized in a number of ways, with ideas being openly proposed, or written privately on cards before making them public. Moreover, the facilitator may or not propose some kind of exchange mechanism between individuals, so that new ideas can be generated by building on ideas set forth by others. Finally, the brainstorming session can be carried out in a neutral environment that does not bear any reference to the product, or in a workshop setting that is strongly associated to it. In this latter case, designers can see and touch the product, may be shown videos of the product in use, etc.
- **SCAMPER** (Eberle 1996) is a complementary technique to brainstorming, and provides some additional guidance to the idea generation process. In a nutshell, participants are required to suggest ideas belonging to the categories for which

the term SCAMPER is an acronym. Therefore, ideas are formulated by using the verbs "substitute", "combine", "adapt", "modify" (or "magnify", "mignify", "multiply"), "put to other use", "eliminate" and "reverse" (or "rearrange"), while the facilitator tries to ensure that each category is sufficiently represented.
- **Synectics*** (Gordon 1961; Prince 1970), though originally proposed as a more general and ambitious methodology, can be viewed as an evolution of brainstorming that is aimed at generating ideas through metaphors and analogies. Synectics also advocates the principle of setting known elements aside ("*make the familiar strange*") while embracing strange and seemingly irrelevant solutions ("*make the strange familiar*").
- **Wish and wonder** and **law-breaking**. These variants to brainstorming may be used to make designers break loose from constraints and allow a freer flow of creative ideas. The team is invited to pretend they can operate in an ideal world in which phenomena occur quite differently than usual. The solutions thus generated cannot usually be applied straight away, but might work with some adaptation. In order to bring participants out of their "comfort zone", the facilitator might pick on well-known references in literature or films. For instance, a design team having to develop medical devices may be invited to pretend they are living in Alice's Wonderland and have to fulfill the desired functions after having been shrunk to the size of a pinhead.

As noted by Girotra et al. (2010), the idea generation process is not easy and straightforward to carry out. In fact, the purpose of the process should not be to generate a large number of ideas of medium or even high average quality. The aim should be to come up with a significant number of exceptional ideas, among which at least one might be viable and lead to the desired degree of innovation. Moving from simply "good" to "great" (though possible a bit crazy) ideas depends first of all on the facilitator's experience, but also on participants' disposition and capability. In many organizations, working with creativity techniques is strongly resisted because of cognitive inertia and people's dislike of challenging the status quo, not counting the hesitation many would have before "making themselves a fool" by proposing potentially silly ideas. Because of this, creativity techniques require an appropriate organizational culture, some training, and a correct balancing between work being done in groups and individual research, during which each designer has greater freedom to think and generate new ideas.

#### 15.1.5.3 TRIZ—The Theory of Inventive Problem Solving

Though it could have been listed among the previous creativity-fostering techniques, TRIZ is such a deep and well-known methodology that it deserves a separate discussion. TRIZ, or the Theory of Inventive Problem Solving*, comes from the intuition of a Russian scientist, Genrich Altshuller. While working for the technical corps of the Soviet Navy, Altshuller tried to develop a general theory on inventions and their underlying principles. He was jailed for political reasons, and

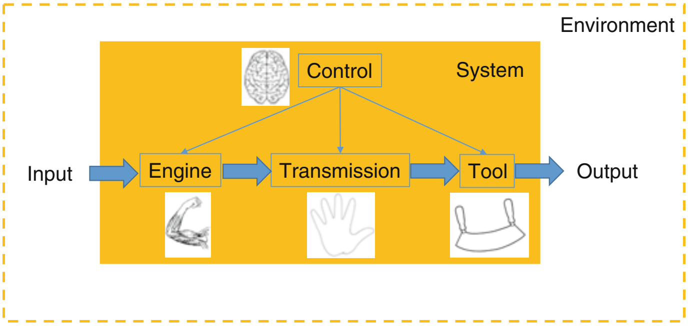


**Fig. 15.13** A technical system according to TRIZ

while interned in a labor camp he went on studying and analyzing patented inventions. After being freed, the results of his work were published and, since the end of the Cold War, have been widely diffused outside Russia. In recent years, TRIZ has been the subject of many training courses and embedded in software tools that have made the method easier to approach, thus assisting its diffusion.

TRIZ is based on the analysis of a vast number of inventions and on the attempt to induce general rules and principles that explain how a designer can creatively tackle a problem in order to generate inventive solutions. Altshuller originally worked on 40,000 patents, but the number analyzed by the TRIZ community has now passed one million.

TRIZ is first of all based on the idea that any Technical System (TS) capable to deliver a function consists of four elements (Fig. 15.13).

- a **Tool**, which is the working element that delivers the function of the TS;
- an **Engine**, which is the element providing the energy required by the tool to produce the expected effect of the function;
- a **Transmission**, which brings energy from the Engine to the Tool;
- a **Control**, which is an element that governs one or more of the previous elements.

Moreover, technical systems evolve in time, usually in the direction of reducing human involvement. For instance, if the required function is to cut and slice vegetables, the traditional TS is made up of a tool (a device with a blade, such as a knife or a crescent cutter), a transmission (the hand), an engine (arm muscles) and a control (eyes and brain). According to what Altshuller called the first law of evolution, the design of the system will evolve in a way that increases technical performance and progressively substitutes human activity with artificial means (e.g., think of the way with which the four elements are embodied in a modern food processor).

This evolution requires the solution of technical problems that have to do with contradictions. *Contradictions* are conflicts between a system and its environment, or between the components of the system itself. Whenever there is a contradiction,

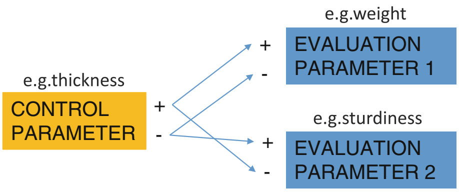


**Fig. 15.14** The concept of contradiction in technical systems

this can be expressed into its most elementary form by means of three elements, as shown in Fig. 15.14: one "control variable" on which the designer can act, and two "evaluation parameters" whose values depend on the control variable. A contradiction arises if, by changing the control variable, the effect on one parameter is beneficial and the other is harmful.

For instance, a table should be sturdy so that one can safely work on it, but also light enough so that it can be easily moved around. A control variable that affects both of these parameters is the thickness of the tabletop. However, this leads to a contradiction, since a greater thickness ensures sturdiness, but makes the table heavier.

After having analyzed a very large number of inventions, Altshuller realized that contradictions occurred among a relatively limited number of features, or

**Table 15.3** Contradiction instances according to TRIZ

| ID | Istance | ID | Istance |
|---|---|---|---|
| 1 | Weight of moving object | 21 | Power |
| 2 | Weight of non-moving object | 22 | Waste of energy |
| 3 | Length of moving object | 23 | Waste of substance |
| 4 | Length of non-moving object | 24 | Loss of information |
| 5 | Area of moving object | 25 | Waste of time |
| 6 | Area of non-moving object | 26 | Amount of substance |
| 7 | Volume of moving object | 27 | Reliability |
| 8 | Volume of non-moving object | 28 | Accuracy of measurement |
| 9 | Speed | 29 | Accuracy of manufacturing |
| 10 | Force | 30 | Harmful factors acting on object |
| 11 | Tension/pressure | 31 | Harmful side-effects |
| 12 | Shape | 32 | Ease of manufacture |
| 13 | Stability of object (resistance to change) | 33 | Ease of use |
| 14 | Strength | 34 | Ease of repair |
| 15 | Durability of moving object | 35 | Adaptability (to external conditions) |
| 16 | Durability of non-moving object | 36 | Complexity of device |
| 17 | Temperature | 37 | Complexity of control |
| 18 | Brightness | 38 | Level of automation |
| 19 | Energy spent by moving object | 39 | Productivity |
| 20 | Energy spent by non-moving object | | |

*contradiction instances,* and came out with a list of 39 (Table 15.3). If contradictions are asymmetrical, the number of possible pairwise contradictions will therefore amount to $39 \times (39 - 1) = 1482$, which is a high number indeed. In Altshuller's original thinking, these contradictions should have been used as the main guiding principle for design.

Given a contradiction, a designer will have to find a "solving approach" for dealing with it. Altshuller identified three main approaches, which are shown in Fig. 15.15.

- *Satisficing* the contradictory requirement consists in understanding the contradiction and looking for a compromise solution. Most of the time, this will simply lead to finding an acceptable tradeoff, without making any substantial change in the underlying technical solutions. This leads to the least inventive results and to incremental innovations that do not depart from the original paradigm. In other cases, the satisfaction of the contradiction will be achieved by a radical change in technology, which will therefore lead to radical innovations and—potentially—to a paradigm shift.
- *Bypassing* the contradiction. This is an explicit decision not to deal with the contradiction at all, and to focus design effort on other contradictions that characterize the design problem.
- Overcoming the contradiction by finding technical means that allow the *separation* of the contradictory requirements. This approach can lead to highly innovative solutions, typically consisting in change to product architecture.

The concept of "separation" is at the heart of Altshuller's contribution. In his review of patents, he concluded that the most significant "inventive steps" were the ones in which the inventor had been able to reconceive the product in a way that contradictions were removed, instead of simply managed. Given the definition of contradiction shown in Fig. 15.14, the only way to remove it consists in separate the elements that are associated to the conflicting evaluation parameters. Such a separation can be made in four different ways (i.e., in space, in time, between parts and the system, and between states). For instance, "separation in space" means physically splitting the two components that lead to a contradiction.[11] With "separation in time", instead, the designer looks at the process of using the artifact, and restructures it so that that the contradiction does not show up any more.[12]

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[11]For instance, the tabletop problem can be solved by deciding for a sandwich structure, with two thin layers of a sturdy and heavy material and an interposed lighter material (or even air). Another example can come from aeronautical engineering, where the contradiction between pilot safety and elements such as size, weight, cost, and fuel efficiency of the aircraft can be solved by separating the pilot from the airplane, and conceiving a remotely operated drone.

[12]Another example from aeronautical engineering can be used to illustrate this principle. At low speed and when maneuvering, an ideal airplane wing should be extended, while it should be swept back when cruising at high speed. A variable-sweep wing used in military aircraft can be adjusted according to the need, and is therefore an example of "separation in time".

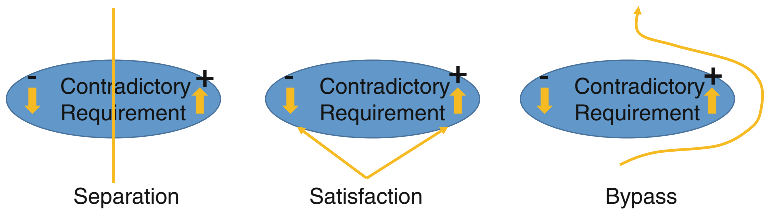


**Fig. 15.15** The three approaches for dealing with contradictions

By classifying patented inventions, Altshuller identified 40 technical "separation principles": among them, for instance, segmentation, asymmetry and anti–weight. Segmentation in its application implies dividing an object into independent parts or making it easy to disassemble, so as to design modular architectures. Asymmetry means aiming at changes in the shape of an object from symmetrical to asymmetrical in order to perform specific functions (e.g., the use of astigmatic optics to merge colors). Anti-weight instead concerns balancing for the weight of an object, by providing lift through the interaction of the object with other objects or with the environment (e.g., aircraft wing shape diminishes air density above and increases it below wing). Finally, he studied their applicability to *each* of the 1482 contradictions and the relationships between contradictions and separation principles allowed the compilation of a "contradiction matrix".[13]

When using TRIZ, a designer can follow the process shown in Fig. 15.16. She must analyze the specific problem at hand and identify the most relevant contradictions. Then, she can use the list of separation principles as a reference and source of inspiration to identify ways to solve the contradictions. Altshuller originally suggested that this process should be followed systematically, using the contradiction matrix as a prescriptive reference of which separation principles should be used to solve a specific type of contradiction. However, practitioners today tend not to use the contradiction matrix any longer.

#### 15.1.5.4 Screening and Selecting Concepts

As it has been mentioned, conceptual design requires a continuous alternation between "divergent" phases, in which concepts are created or improved, and "convergent" phases, that reduce the size of the concept pool. In general, one can distinguish between screening and final selection. Screening has the purpose of reducing the number of candidate concepts generated by a previous "divergent" phase to a manageable number, so that they can later be developed and improved, often by recombining them. Screening therefore does not have the aim of selecting the best

[13]The contradiction matrix is obviously too large to be presented on paper, but can be found online at http://www.innovation-triz.com/TRIZ40/TRIZ_Matrix.xls.

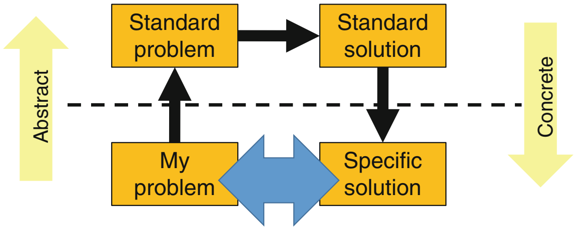


**Fig. 15.16** The process for applying TRIZ to a technical problem

candidate concept(s), but of weeding out the ones that are very unlikely to be fit for purpose. Conversely, concept selection has the objective of singling out the "best" concept that will be developed during the subsequent embodiment design phase.

The screening and selection of concepts will obviously depend on a number of different criteria. These will have some relation to the key technical features and user needs that emerged during the requirements analysis phase as, for instance, through a QFD analysis. If this analysis has been properly carried out, the design team should have a quite clear and "objective" picture of the criteria and of their weights. So, a method for concept screening and selection will necessarily be based on some sort of multicriteria analysis. Given the limited time available, one might suggest a relatively straightforward approach such as AHP (which has already been mentioned in Chap. 9, when dealing with project selection problems, Saaty 1980), and leave aside more formal and structured multicriteria methods (Roy 1996; Belton and Steward 2002). However, in practice, firms tend to use even simpler tabular multicriteria methods, as will be described in the following.

Screening and selection can be performed by using Pugh comparison tables (Pugh 1981, Fig. 15.17) in which each concept is evaluated on each relevant criterion on a relatively simple five-level evaluation scale ("−2" if the concept is likely to perform significantly worse than the average product on that criterion, "0" if it will probably perform close to average, "2" if it will perform significantly better, and "−1" and "+1" in case of intermediate evaluations). The overall score of each concept is simply given by the sum of these criterion-level scores. When screening concepts, the method allows creating three groups of candidates, i.e., "very promising" concepts that have good to high scores on all criteria, "interesting" concepts that have high scores on some criteria, but low scores on other ones and, finally, "unpromising" concepts that have low scores on all criteria and are therefore dominated by concepts in the "promising" set. When used properly, the design team will use the Pugh comparison table to select the "promising" group of concepts, and to subject the "interesting" group to a more thorough analysis. In the subsequent steps, it would in fact be advisable to "prune" the smart ideas that determine the strengths of this latter group and try to "graft" them onto the concepts belonging to the former, in order to further reduce their weaknesses.

Conversely, when making the final selection, one would simply pick the highest-ranking concept and push it forward to the embodiment design phase.

| |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
| Safety risk | --- | -- | -- | -- | + | -- | + | +++ | +++ | - |
| False operation | --- | - | - | + | ++ | + | + | + | ++ | ++ |
| Required force | --- | -- | -- | - | + | + | ++ | ++ | +++ | +++ |
| Compactness | + | +++ | ++ | +++ | +++ | ++ | ++ | ++ | - | - |
| Usability | - | + | - | ++ | +++ | ++ | + | ++ | +++ | ++ |
| Volume | +++ | + | + | + | + | + | + | + | + | + |
| Weight | +++ | + | + | + | + | + | + | + | + | + |
| Production cost | ++ | ++ | + | + | + | + | - | + | -- | -- |
| $\sum +$ | 9 | 8 | 5 | 9 | 13 | 9 | 9 | 13 | 13 | 9 |
| $\sum -$ | 10 | 5 | 6 | 3 | 0 | 2 | 1 | 9 | 3 | 4 |

**Fig. 15.17** A Pugh comparison table for concept selection

| | |  |  |  |  |
|---|---|---|---|---|---|
| Safety risk | 15 | 1 | 3 | 3 | 5 |
| False operation | 12 | 3 | 4 | 3 | 4 |
| Required force | 20 | 2 | 3 | 5 | 5 |
| Portability | 6 | 5 | 4 | 2 | 2 |
| Usability | 15 | 4 | 5 | 3 | 5 |
| Volume | 8 | 5 | 3 | 2 | 1 |
| Weight | 12 | 5 | 3 | 3 | 1 |
| Production cost | 12 | 5 | 5 | 2 | 1 |
| $\sum$ | | 341 | 372 | 314 | 342 |

**Fig. 15.18** A weighted scoring table for concept selection

As a variant of Pugh comparison tables, one may also use weighted scoring matrices, with criterion weights normalized so that they sum to 100, and using a 1–5 scoring scale for evaluating each concept on each criterion (Fig. 15.18). The difference between these matrices and Pugh tables is due to the fact that criteria are weighted, thus allowing a finer comparison of alternatives. Therefore, weighted scoring matrices are generally used for the final selection of the product concept, and not in the earlier screening phase.

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# Chapter 16
# Design and Redesign of Product Architecture

This chapter deepens the discussion on the design of products and systems that started in Chap. 15. At first, we will consider the design of product architecture, and then propose techniques that are used to this purpose especially when redesigning existing products. Given the aim of this textbook to remain neutral with respect to fields of technology and industries, this chapter will end the discussion on product design and development. Going further into the areas of embodiment and detailed design would require tackling domain-specific considerations that would be outside our scope. Moreover, it might lead to engage in topics that—to date—still are object of discussion, and are not diffused enough in industry.

## 16.1 Defining Product Architecture

The concept of product architecture has now and again appeared in the pages of this text. It has been initially defined as "*the components of the product and their functional relationships*" when discussing Henderson and Clark's taxonomy of innovation (Chap. 3), highlighting the role that product architecture has in shaping organizational routines and therefore leading to organizational inertia. When looking at a product from a deeper technical perspective, as it is being done now, the definition of product architecture can be rephrased, adding some details and discussing the manifold implications that architecture has on the product, on the firm, and on its supply chain.

According to a widely accepted definition, product architecture is defined by "*the relationships between its functional elements*, *the mapping among functional elements and physical components and the interfaces among physical components*" (Ulrich 1995). With this new definition, the focus now extends from components to functional elements, and centers on the interface between the function tree and the lower echelon of the product Bill of Materials.

With this definition in mind, architectures can be classified according to the mapping between functional elements and physical components:



M. Cantamessa and F. Montagna, *Management of Innovation and Product Development*, DOI 10.1007/978-1-4471-6723-5_16

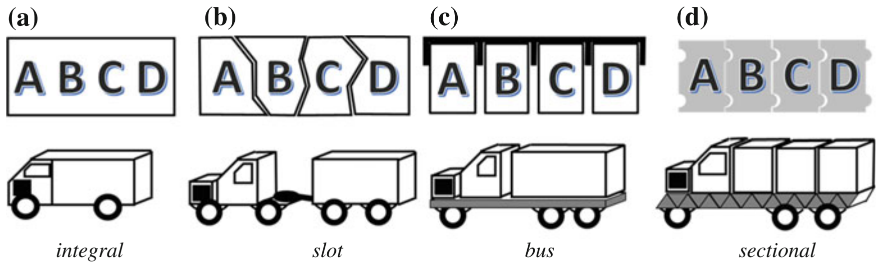



**Fig. 16.1** Alternative architectures for two products (as proposed by Ulrich 1995). **a** Integral, **b** slot, **c** bus, **d** sectional

- *Integral architectures* are characterized by functional interdependence between components, with each function being fulfilled by multiple components and components embodying multiple functions.
- *Modular architectures* are, instead, characterized by functionally independent components. Each component therefore is in charge of implementing a single function, and each function is fulfilled by a single component. In turn, modular architectures can be *slot-based*, if the interconnections between pairs of components are not based on a standard interface. A modular architecture will be *sectional* if the interface between each pair of interconnected components is standardized. Finally, in a *bus-based* modular architecture, components will not be directly connected with each other, but through a common component (called *bus*) and using a standardized interface.

Figure 16.1 provides examples of two products that might be implemented by means of alternative architectures. Of course, some of these alternatives are practically relevant, while others may be less so.

In principle, this classification of product architecture should apply to the entire product. However, it is possible for complex artifacts to exhibit portions that appear to be integral, while other ones may instead be modular.

Concerning interfaces in a given product architecture, these may be *coupled* or *uncoupled*. In the former case, a parametric change in one of the connected components will propagate to the other component and require at least a partial redesign (e.g., thickness of component (a) in Fig. 16.2, left-hand side). Conversely, in an uncoupled interface, a change in one component will not affect the other (Fig. 16.2, right-hand side). In general, coupled interfaces provide a tighter connection among components but—at the same time—make detailed design of the artifact significantly more complex because of change propagation.

The type of architecture that is used by a firm casts a strong influence on aspects that are relevant at both tactical and strategic level. The following discussion explores these influences, and may be used either to foresee likely consequences

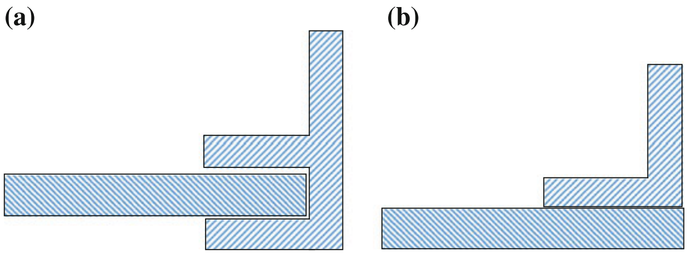



**Fig. 16.2** Couple and Uncoupled interfaces

that will emerge because of a given product architecture, and as a guideline for choosing a product architecture that may lead to desired outcomes.

### 16.1.1 Product Performance

Product performance depends on either *localized* or *general* performance variables. The former variables are relevant at product level, but their value can be directly traced to a corresponding performance in a specific subsystem (e.g., the mass memory capacity of a computer is given by the capacity of its hard disk drive). The latter are performance variables whose values depend on a corresponding performance that is distributed across multiple subsystems. For instance, mass and cost of a personal computer are given by the sum of the corresponding values for all subsystems. Similarly, operating time when working on batteries will jointly be given by the capacity of its batteries (in Ampere-hours) and by the power consumption (in Watts) of its components.

With a modular architecture, it will be easy to design a system with the objective of enhancing localized performance variables, since this simply requires choosing and/or designing components that match these requirements. However, the 1:1 relationship between functions and components that characterizes a modular architecture will prevent function sharing, which is generally a good way to enhance general performances. Conversely, an integral architecture will be likely to lead to an improvement in general performances, but at the expense of localized ones.

### 16.1.2 Product Change

Product change can be associated to variations that occur within the lifetime of an individual product in the hands of its user, as well as changes introduced by the firm over the product lifecycle.

The first perspective involves introducing actions such as:

- **upgrades**, which consist in the substitution of individual components in order to enhance localized performances (e.g., inserting a hard disk drive with greater capacity in a computer system);
- **add-ons**, or additions of a component, so that the product can deliver new functions (e.g., addition of an external lighting source on a video-camera);
- **functional variety**, consisting in the substitution of components, in order to increase the range of activities that the product can fulfill (e.g., exchangeable lenses in cameras);
- **adaptations**, or substitution of components that allow the product to operate in different conditions of use (e.g., an adapter that allows powering a device from an AC socket or in a car);
- **substitution** of worn-out or exhausted parts (e.g., toner cartridges).

Product change is generally easier for products with modular architectures, since components can be changed without redesigning the whole product. Moreover, modular architectures can open the road for these components to be developed, manufactured and sold by third-party producers. The firm developing the main product must be fully aware of the strategic consequences of this opportunity, given the obvious tradeoff between losing part of the margins, at the same time increasing customer value without having to make investments. In some cases, the tradeoff leans heavily toward "closing the product" off to third parties (e.g., ink cartridges for a printer maker that relies on a razor-blade business model). In other cases, the tradeoff may hint at greater opening (e.g., the plethora of accessories that can make a smartphone appealing to consumers).

The other perspective on product change looks at modifications introduced by the firm over the product lifecycle. This has to do with the concept of "*component carryover*" between successive product releases. In general, component carryover can be expressed as the percentage of components (or component value) that a new product inherits from its predecessor. It is intuitive that a modular product will make it relatively easy to redesign a product by substituting part of its components, and without having to redesign the other ones. Conversely, the tight intercomponent relationships that characterize an integral architecture could require the redesign of all—or most of—its components.

On a strategic level, the adoption of modular architectures allow firms to develop "platform-based products", in which a common platform enables the quick and effortless development of product derivatives catering to specific and contingent market needs. Thanks to modularity, derivative-specific components can be designed without having to redesign the core and "in-platform" components.

If a firm becomes very quick in exploiting modular architectures and modifying its product offering, it may reduce its reliance on market research, and use actual market acceptance as a guidance tool. Taken to the extreme, firms can choose to adopt the concept of "real-time market research", and gradually modify their products and services, based on the feedback they progressively receive from the market.

### 16.1.3 Product Variety

Modular architectures and platform products do not only allow a quick change between successive product releases and product generations but also the simultaneous offering of differentiated product variants based on the common platform. This strategy can lead to three main advantages:

- the firm is able to address multiple horizontally and vertically differentiated market segments, with obvious benefits for its pricing power;
- in-platform components are produced in significant volumes, which can lead to significant economies of scale;
- the overall effort spent in developing the platform and product derivatives can also lead to economies of scale, because of the high volume that comes from all the product variants being offered.

Moreover, modular architectures can enable the offering of products characterized by combinatorial variety, in which a core product can easily be customized by adding or changing of number of components. For instance, if a customer can configure her product by choosing among two variants for $n$ of its modules, the number of potential product variants becomes $2^n$. Thanks to combinatorial variety, the firm can make a strategic upstream shift of its Customer Order Decoupling Point (i.e., the instant at which customer orders are accepted) and move from "Make-To-Stock" to "Assemble-To-Order" operations.

Going on even further, and given that major economies of scale usually occur at component manufacturing level rather than at final assembly, the firm may opt to fragment assembly operations and locate them closer to the customer. For instance, a firm may decide to centrally retain the manufacturing of the core part of the product, but let to local dealerships the task of completing customization and assembly of the final product. In some cases, these local "*miniplants*" may be given the task of creating their own supplier base and of locally sourcing non-core components with high transportation costs, for which centralized manufacturing would not be justified (e.g., shovels and scoops used in earth moving machines).

Finally, a highly modular architecture can lead a firm to commercialize a broad variety of elementary and interoperable building blocks, leaving the task of structuring the final "product" to customers or vendor/installers. This is the typical case of computer networking and electrical equipment, which are assembled into an actual system by installers.

In general, integral architectures do not lend themselves well to supporting product variety. However, there might be exceptions. For instance, in the case of relatively simple products that are produced in very high volumes, an integral architecture may allow an extreme simplification of the bill of materials (e.g., disposable razors) and thus facilitate product variety. Moreover, if one thinks of the flexibility granted by modern manufacturing technology (e.g., NC machining centers, additive manufacturing techniques, etc.), one-off products with complex shapes can be produced with relative ease, though not in high volumes.

### 16.1.4 Standardization

Because of component decoupling, modular architectures also make it easier to use standard—instead of purpose-designed—components. Standardization can here be conceived both in its extensive and “industry-wide” meaning, as discussed in previous Chap. 4, as well as in a narrower and company-wide sense. Standardization of components leads to obvious advantages because of economies of scale and reduction of complexity. However, these advantages will be balanced by additional costs, since having to choose among a limited set of standardized components will lead to over-dimensioning with respect to the needs of the specific application. In some cases, the overall product requirements may be so stringent (e.g., the weight of airborne systems) that this becomes unacceptable.

### 16.1.5 Influence on the Organization and on the Supply Chain

In general, modular architectures lead to a significant decrease in the intensity of information flow between the designers that are in charge of developing each component. If functional relationships between components are relatively loose, the same component can readily be used in different products, thus leading to economies of scale. Moreover, a designer who is developing a component can focus on its performance, rather than spending time on issues pertaining to its integration in the product, and this also favors the rise of experience economies. Therefore, modular architectures will often be associated with a low degree of vertical integration between producers of the end product and producers of modules and components. This leads to a clear separation in the roles and competencies developed by each party. Producers of the final product will have to develop systems engineering skills and focus on integration issues, while component producers will concentrate on the specific requirements of the individual components.

Depending on the degree of separation between producers of the final product and suppliers, it is common to distinguish among “*black-box*”, “*white-box*” and “*gray-box*” product development. In the former, the producer of the end product does not look into the inner workings of the components at all, but limits herself to specifying and testing the features and performances she thinks are relevant. With “white box” development, the producer has a direct influence on the development of components and—of course—this requires her to be proficient in the related technology. “Gray box” development can be viewed as an intermediate approach, in which the producer has a sufficient understanding of the issues that are relevant to the development of the components, but restrains herself from having a direct influence on suppliers’ choices.

Functional interdependencies strongly influence the strategic choice made by firms in a supply chain concerning which product components they will develop and produce. Empirical research in the automotive supply chain (Cantamessa et al. 2006) has shown that firms specialize in developing and producing components according to similarity of underlying technology, adjacency of components in the final assembly, and functional interdependencies. However, the strongest of these three factors in explaining firms' specialization choices appears to be the pattern of functional interdependencies.

The previous discussion has focused on the impact of product architecture on the supply chain. If one looks at the level of project management, architectural choices lead to quite different management strategies. In the case of modular architectures, the project manager behaves as a "system architect". His major focus is on the specification of components, while detailed design is delegated to designers and design teams. These designers engage in a customer-supplier relationship with him, and may work in parallel without significant interaction among each other. Verification and testing can be performed toward the end of the development process, with the main objective of validating system performance and of identifying unexpected interactions between components.

Conversely, in the case of an integral architecture, the project manager will have to operate as a "system integrator". Most of her effort will be dedicated to the continuous coordination and negotiation with the designers in charge of developing components. Designers will have very close reciprocal interactions, both at a formal and an informal level, in order to "iron out" all inconsistencies among their design outcomes. Verification and testing are performed continuously as a "fine tuning" of the system, in order to bring performance in line with the expected specifications.

## 16.2 The Design of Product Architecture

The previous discussion has given an indication on the type of architecture—i.e., integral versus modular—that could be preferable, given the product, strategy and supply chain the firm is operating in. Especially when dealing with products with moderate to high complexity, designing the product architecture means something more. Given the complex web of relationships between functional elements, the designer will have to look for an aggregation of the components into modules that are relatively independent of one another, and that might exhibit significant interdependencies within.

This activity can be performed either intuitively or analytically. In the former case, the designers can use functional block diagrams (such as the ones introduced in Chap. 15) and visually identify "*chunks*" of components (or modules) that exhibit a high degree of interrelationships, at the same time with limited interactions with components belonging to other chunks. When analyzing functional block diagrams, one may use rules of thumb such as the following (Stone et al. 1998):

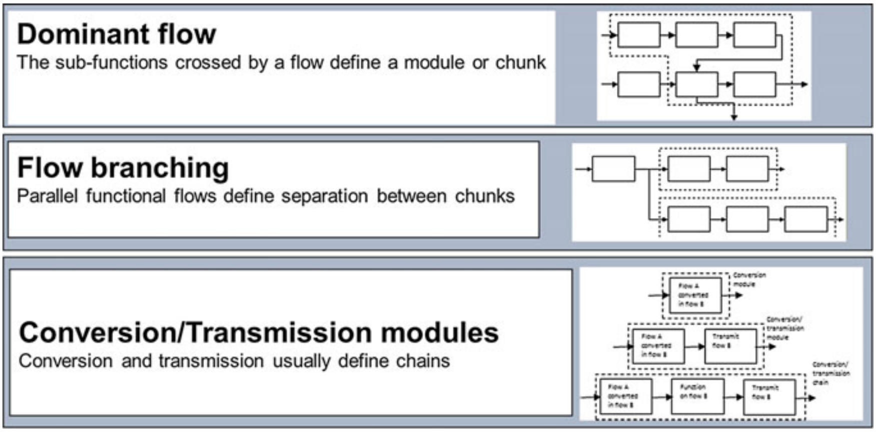



**Fig. 16.3** Visual identification of component chunks, based on a functional *block diagram*

- **Dominant flow**. Functional elements crossed by a single “flow” and that do not “branch out” to other functional elements are good candidates for being assigned to a same chunk.
- **Branching**. When one observes “branching” in a flow, this is an indicator that each branch should probably be assigned to separate modules.
- **Conversion and transmission**. Elements whose function is the conversion and transmission of material, energy or information, will generally go in the same, dedicated, module.

Figure 16.3 shows an example of a visual analysis carried out on a product block diagram, leading to a definition of product architecture.

When products are quite complex and/or when the firm wants to carry out a rigorous analysis, intercomponent relationships can be represented with adjacency matrices (Fig. 16.4a). In the adjacency matrix $A = [a_{ii'}]$, $a_{ii'}$ represents the strength

**(a)**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Component 1 | | 2 | | | |
| Component 2 | 2 | | 1 | | |
| Component 3 | | 1 | | 2 | 2 |
| Component 4 | | | 2 | | 2 |
| Component 5 | | | 2 | 2 | |

**(b)**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Component 1 | 3 7<br>3 | 2 1<br>-1 0 | | | |
| Component 2 | 2 1<br>-1 0 | 8<br>8 7 | 1 1<br>1 0 | | |
| Component 3 | | 1 1<br>1 0 | 5<br>5 4 | 1 0<br>-1 | 2 1<br>0 1 |
| Component 4 | | | 2 0<br>-1 | 1 2 3<br>1 4 | 2 3 |
| Component 5 | | | 2 1<br>0 1 | 2 3 | 3 2 1 |

s=space e=energy
i=information m=materials

| | |
|---|---|
| s | e |
| i | m |

On the diagonal: properties A, B, C, D, E, F

| | | |
|---|---|---|
| A | B | C |
| D | E | F |

**Fig. 16.4** Identification of inter-component relationships with adjacency matrices

of the relationship between component $i$ and component $i'$. This can be expressed in as a continuous and nonnegative parameter in the range $[0 \ldots M]$, with 0 meaning there is no connection between the two components and $M$ that there is a very strong relationship. For simplicity, this can be reduced to a Boolean parameter indicating presence or absence of a relationship between components.

Parameter $a_{ii'}$ can also be computed as the aggregation of intercomponent relationships associated to different perspectives, such as functional interactions, reciprocal disturbances, ease of assembly. In some instances, relationships between two components may lead to opposing conclusions, suggesting on the one side to place the two together in the same chunk and, from another perspective, to keep them apart. This typically occurs when one of the relationships is harmful (e.g., if component 1 generates heat and components 2 must operate at a low temperature). In order to represent this possibility, parameters in the adjacency matrix may be assigned both positive and negative values in the range $[-M \ldots M]$, with negative values indicating a harmful relationship (Fig. 16.4b). It may be useful to remind that representing multiple perspectives in intercomponent relationships can be easily done by using the Rodenacker notation discussed in Chap. 15.

Based on the adjacency matrix $A$, components can be assigned to chunks, so that the sum of adjacency measures between components belonging to the same chunks is maximized, at the same time minimizing the sum of adjacency measures between components that are assigned to different chunks.

Figure 16.5 provides a simple example of this kind of calculations, showing how a functional decomposition based on adjacency measures (top right) can lead to a completely different architecture than the one obtained through an "intuitive" approach based on similarity of underlying technology (bottom right).

The value of this approach does not only lie in providing a mathematical support to defining product architecture. Rather, its value lies in the dialogue that the design team will be forced into having when defining the values that go in matrix $A$. This dialogue can lead to a strong and valuable mutual understanding of design issues, and can easily lead to challenging established ways for conceiving the product. In the previous example, the "optimal" and counterintuitive decomposition at the top is due to the "$-1$" adjacency value between "switch" and "cord". In turn, this value may have been decided by the team in order to affirm the opportunity of allowing last-minute fitting of different cords to the appliance.

Intercomponent relationships which—as we have seen—can be represented by means of block diagrams or through matrices, are generally associated to a given technological state of the art. These relationships can be studied when working at a strategic level on technology roadmaps, in order to foresee the architectural impact of an up and coming technology, which may create or break architectural linkages between components. Conversely, the matrices can be used to identify which technology might be desirable for modifying intercomponent linkages, and therefore lead to a desired architecture.

As a historical example, one can think of automobiles between the '70s and the '80 s. At that time, radiator fans were engine-driven, i.e., directly powered by the crankshaft. Since the fan and the radiator have to be mounted at the front of the car,

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Blade 1 | | 2 | | | | | |
| Axis 2 | 2 | | | | 2 | | |
| Electric cord 3 | | | | -1 | | | |
| Switch 4 | | | -1 | | 2 | 2 | |
| Electric motor 5 | | 2 | | 2 | | 2 | |
| Chassis 6 | | | | 2 | 2 | | 2 |
| Transparent cup 7 | | | | | | 2 | |

Functional decomposition

| | 1 | 2 | 4 | 5 | 6 | 7 | 3 |
|---|---|---|---|---|---|---|---|
| Blade | | 2 | | | | | |
| Axis | 2 | | | 2 | | | |
| Switch | | | | 2 | 2 | | -1 |
| Electric Motor | | 2 | 2 | | 2 | | |
| Chassis | | | 2 | 2 | | 2 | |
| Transparent cup | | | | | 2 | | |
| Electric cord | | | -1 | | | | |

Score $= \boldsymbol{\Sigma}$ (internal to chunks) – $\boldsymbol{\Sigma}$ (external to chunks) = (2 * 5) - (2 - 1) = 9

Technology-based decomposition

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Blade 1 | | 2 | | | | | |
| Axis 2 | 2 | | | | 2 | | |
| Electric cord 3 | | | | -1 | | | |
| Switch 4 | | | -1 | | 2 | 2 | |
| Electric motor 5 | | 2 | | 2 | | 2 | |
| Chassis 6 | | | | 2 | 2 | | 2 |
| Transparent cup 7 | | | | | | 2 | |

Score $= \boldsymbol{\Sigma}$ (internal to chunks) – $\boldsymbol{\Sigma}$ (external to chunks) = (2 * 3 - 1) - (2 * 3) = -1

**Fig. 16.5** Decomposition in chunks based on adjacency measures

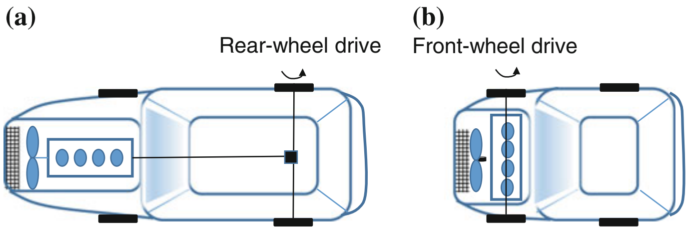



**Fig. 16.6** An example of removal of architectural constraints

this cast a constraint on vehicle architecture: powering the fan is easier if the engine is placed longitudinally and—in turn—a longitudinal engine naturally lends itself to adopting rear wheel drive (Fig. 16.6, left-hand side). These constraints made it quite difficult to design compact cars with ample floorplan in the cockpit, which would have required a transverse engine layout and front-wheel drive. The architectural coupling was broken thanks to the introduction of electric thermostatic fans, which made it easier to place engines transversally (Fig. 16.6, right-hand side).

## 16.3 Designing Platform-Based Product Architectures

Platform-based product design has already been outlined as a strategic approach that firms may use in order to efficiently develop a wide variety of products, based on a common set of components and technologies. It goes without saying that a product platform will be closely connected to the architecture that the underlying products will have in common. Therefore, the design of platform-based products will be closely associated to the design of such architecture. This section aims at providing a preliminary presentation of the approaches that can be used when designing the architecture underlying platform products.

At first, it is possible to define a platform as a "set of common assets" on which a product family can be based (Meyer and Lehnerd 1997). When speaking about common assets shared by the products belonging to the family, the most obvious ones are components and subsystems. However, one can widen the scope of "assets" and include common customers and customer relations, common values pertaining to a brand, and common resources involved in product development. The identification of which type of common assets should be part of the platform allows the firm to define the strategic objectives of a platform-based product. In the case of common components, the firm will generally be able to leverage them in order to serve different market segments. In such a case, designers may find it useful to come up with a visual representation of the roadmap showing how the platform will support the launch of a number of horizontally and/or vertically differentiated products (as discussed in Chap. 9). Besides the choice of customer segments, the roadmap must show the timing at which each segment will be addressed. In fact, the

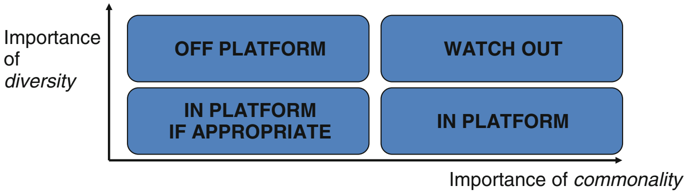



**Fig. 16.7** Mapping components in order to decide platform composition

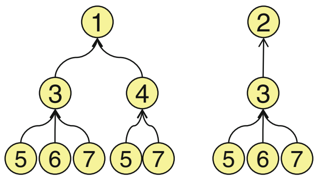
firm may decide for a near simultaneously entry in all customer segments, while in other cases this will occur along a longer time span, starting from an initial "beach-head" segment.

In its most basic form, designing a product platform around a set of common components implies deciding which components must be "in platform" (i.e., common to all products based on the platform) and which should be "off platform". A simple way to operate this choice consists in assigning each component (or subsystem) two scores, one measuring the "value of commonality", the other the "value of specificity", the former expressing the advantages that may come to the firm by sharing the component across the product family, and the latter the importance attributed by customers of having a specific component for each product. These scores can be assigned by expert evaluation, or using objective data on cost-volume curves and customer preferences, respectively.

A two-dimensional map, as in Fig. 16.7, makes it possible to make "visual" decisions on platform-based component sharing. Components with high value of commonality and low value of specificity will be obvious candidates for being shared. For instance, having a single heating and ventilation system in an automotive platform can lead to significant economies of scale, while customers will probably not even be aware that this component is the same for all models in the range. Components with low value of commonality and high value of specificity ought to be taken "off platform". For example, customers will make a strong association between a specific car model and components having a mainly aesthetical value (think of the steering wheel), but the firm will have limited cost disadvantage in producing a different one for each model. Components with low value of commonality and low value of specificity can usually be shared. Finally, critical decisions can arise with components having high values of commonality and specificity. The firm will generally have to decide whether to seek a cost advantage, or lean on customer preferences. In some cases, the components may lend themselves to hybrid solutions. For instance, the component can be shared across products, but some of its features and functions could be modified and/or disabled according to the product it will be installed in (e.g., a low-end digital camera might have the same microprocessor as a high-end one, but use a different firmware that provides image processing algorithms of lesser quality).

In order to properly manage component sharing, a number of metrics have been developed in order to measure the degree with which components are being used in

**(a)** **(b)**




**(c)**

| Component | $\Phi_j$ |
|---|---|
| 1 | n/a |
| 2 | n/a |
| 3 | 2 |
| 4 | 1 |
| 5 | 3 |
| 6 | 2 |
| 7 | 3 |

**Fig. 16.8** Computing commonality measures between products

different products. The basic measure is the number $\Phi_j$ of parents to each component $j$, i.e., the number of instances in which component $j$ appears in the firm's bills-of-material (end items are obviously not considered).

For instance, given the BOMs in Fig. 16.8a, b, one can compute values of $\Phi_j$ (Fig. 16.8c) per each component and then calculate aggregate indicators. One quite simple indicator is the Degree of Commonality Indicator, expressed by (16.1):

$$\mathrm{DCI} = \frac{\sum_j \phi_j}{d} \geq 1 \tag{16.1}$$

The greater the value of DCI, the greater is the degree of component sharing, while DCI = 1 means there is no component sharing at all. In the previous example, DCI = 11/5 = 2.2.

Another similar indicator is the Total Constant Commonality Index, as formulated in (16.2):

$$\mathrm{TCCI} = 1 - \frac{d-1}{\sum_j \phi_j - 1} \in [0, 1] \tag{16.2}$$

The TCCI indicator is bounded in the interval [0, 1], with TCCI = 0 implying no component sharing, and TCCI = 1 the maximum commonality possible. In the previous example, TCCI = (5−1)/(11−1) = 0.6.

## 16.4 Designing Modular Product Architectures

Due to the competitive impact that can derive from modular and platform-based architectures, researchers have proposed a number of techniques aimed at supporting designers in this effort. Among them, Modular Function Deployment* (or

MFD, Ericsson and Erixon 1999), has gained some diffusion in industry, thanks to its intuitive use and to the value provided by relating design decisions to customer needs.

MFD starts with an analysis of customer needs that is very similar to the one performed in QFD. Each of these customer needs is then associated to a degree of relevance of modularity, i.e., a 1–9 score expressing the degree with which modularity might contribute to the satisfaction of each customer need. In turn, this potential contribution of modularity can be systematically analyzed with respect to a number of "modularity drivers".[1]

After this first step, the product is analyzed from a functional perspective, and this leads to a list of "technical solutions" (or, functional elements that are independent from one another).

At this point, the core step of MFD is performed by developing the "Module Indication Matrix" (Fig. 16.9). This is a table that represents the relevance of each modularity driver (in rows) to each technical solution (in columns), with the same {1, 3, 9} scale that is generally used in QFD (where 1 indicates a weak relationship, 3 a significant one, and 9 a very strong one). By summing up these scores across columns, one can understand which of the modularity drivers appear to be more relevant to the product. Conversely, by summing the scores over rows, one can identify the technical solutions for which modularity appears to be of greater importance. Moreover, by analyzing the matrix, the designer can observe clusters of technical solutions that are relevant to a same modularity driver. This can suggest ways for aggregating technical solutions into modules that obey to a same driver.

The MFD method also provides some guidance on the number of modules $m$ that should be planned for a product with $n$ components. In general, each component within a module requires a given effort EC for the various activities associated to it (e.g., design, assembly, testing, etc.), while the development of each module requires an effort $E$. As a rule of thumb, $E = 1 \div 5$ EC. This, being the case, the overall total effort TE associated to the product will be given by

$$\mathrm{TE} = m\,\mathrm{EC} + \frac{n}{m}E \tag{16.3}$$

[1]The drivers originally cited by the authors are (i) economies of scale arising by using the same component across a product family; (ii) economies of scale and economies of learning due to the use of the same component across successive product generations; (iii) absence of specifications forcing the use of a specific component in each product; (iv) styling and aesthetical issues; (v) risk of obsolescence due to planned changes or to technological evolution; (vi) better use of bottleneck resources in R&D or production; (vii) possibility of outsourcing; (viii) possibility of testing the component separately; (ix) easier servicing and maintenance; (x) easier upgrading; and (xi) easier end-of-life treatment. Of course, each firm is free to adapt the list of drivers in order and make them more relevant to its own environment.

| Technical solutions / Driver | TS1 | ... | TSn | Sum |
|---|---|---|---|---|
| Common unit | 1 I 3 I 9 | | | |
| Carryover | | | | |
| Different specification | | | | |
| Styling | | | | |
| Planned product changes | | | | |
| Technology evolution | | | | |
| Process / Organization | | | | |
| Available from supplier | | | | |
| Separate testing | | | | |
| Service / Maintenance | | | | |
| Upgrading | | | | |
| Recycling | | | | |
| **Sum** | | | | |

Which module drivers are most relevant in defining modularity?

Which TSs have similar or compatible drivers? → find the possible m modules by aggregating TSs

To what extent should TS be an independent module?

**Fig. 16.9** The module indication matrix used in modular function deployment

the value of m that minimizes $E$ will therefore be given by

$$m^*|\frac{d\mathrm{TE}}{dm} = 0 \tag{16.4}$$

$$m^* = \sqrt{n\frac{E}{\mathrm{EC}}} = 1 \div 2\sqrt{n} \tag{16.5}$$

## 16.5 Value Analysis and Value Engineering

When designing product architecture, firms must constantly base their decisions on customer needs. One widely known and time-tested method for doing this is *Value Analysis* (VA)*, a technique developed by Lawrence Miles at General Electric during World War II. Miles had the insight that customers buy products because of their ability to produce a useful outcome, and this can be considered to be the "value" of the product.

The value of a product is quite a complex concept, that an economist could in first instance associate with the "reservation price", i.e., the price at which a given customer would be indifferent between buying and not buying the product (or, in layman's terms, the maximum amount the customer would be willing to pay). In order to have a better grasp on value as a concept, it is possible to tackle it from three different perspectives. *Use value* comes by estimating the value of a product from its quantifiable benefits (e.g., time saved, profit accrued, etc.). Use value is generally appropriate for instrumental goods bought by businesses (e.g., a machine tool) but can sometimes be applicable to consumer goods as well. In other cases, and especially in the case of consumer goods, customers base their choices on a wider concept of value, called *esteem value*, in which other intangible elements come into play (taste, aesthetics, the role of the product as a status symbol, etc.). Finally, one may consider the concept of *market value*, which is the price a customer would expect to pay, given the intrinsic value of the good (which is associated to use and/or esteem value) and the existence of competing products. The difference between use and/or esteem value and market value (or price) is the surplus that the consumer is left with, after purchasing the product. The difference between price and cost is—of course—the margin that goes to the firm.

If one understands the concept of value, it should be quite clear that a firm should not design and redesign its products with the simple objective of reducing cost, since this action might actually lead to reducing value as well. Instead, firms should maximize the difference between value and cost. This can also be said to be equivalent to reducing "waste", intended as any element that has a cost but does not add value. By referring to Fig. 16.10, and starting from the baseline case on the left, one can see three ways with which a firm may redesign its products. Alternative (a) exemplifies a cost reduction that destroys value: the cost reduction makes the product less attractive to such an extent that value is reduced by an even greater amount. This ultimately leaves the customer with less surplus, and the firm with less profit. Alternative (b) shows a cost reduction that does not modify the perception of the product. Its use/esteem value is unaltered, so that the firm can keep the same price, thus internalizing the value created as profit. Finally, alternative (c) shows a cost increase that actually creates value, since it leads to an improved product that exhibits an even greater increase in value.

The VA method aims at guiding firms through the process of making the right design and redesign decisions with respect to these issues. In general, the method is implemented by product development teams with representatives coming from different functions, who meet regularly (i.e., once a week) for a sequence of sessions dedicated to analyzing the product, brainstorming for solutions, and then

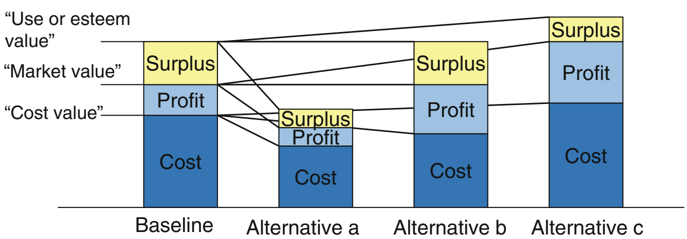



**Fig. 16.10** Redesign alternatives and their impact on value


**Fig. 16.11** The product redesign process in VA

deciding on the changes to be made (Fig. 16.11). In preparation to the meetings, participants are usually assigned tasks for gathering data on the existing product (prior to analysis) and on the viability of proposed solutions (prior to decision making). As in all interfunctional activities, it is critical that the organization at large, and the people involved, are sufficiently committed and share a common objective (e.g., "*we will redesign product X in four weeks' time*, *with the objective of reducing variable cost by* 7.5 %"). Absent such commitment both during the meetings and in the in-between activities, it would be quite likely to end up with a failed project.

VA originated in the field of manufacturing, and we will present it in this context. However, the method is readily adaptable to services as well.

VA is usually carried out in four phases of growing complexity. The first two phases usually go under the actual name of "VA", and cope with the redesign of a current product, which implies that modifications will be somewhat constrained. The third phase is better known as "Value Engineering" and is usually concerned with a more substantial degree of product redesign. The fourth phase aims at rationalizing and extending the outcomes of the first three. These phases are described in the following.

### *16.5.1 Phase 1—Obtaining the Same Product at a Lower Cost*

During this phase, the VA team is tasked with analyzing the items in the product Bill of Materials one by one, and proposing changes that will alter neither the functions, nor the overall product and its architecture, but only the individual components. Examples of such proposals include changing materials, suppliers, process technology, reversing previous "make or buy" choices, and altering the detailed design of components (e.g., shapes, dimensions, tolerances). The rationale behind this phase lies in the uncertainty that might have led to specific choices when the product had been initially designed. For instance, in choosing between a labor-intensive process (with low fixed cost and high variable cost) and a capital-intensive process (with high fixed cost and low variable cost) a firm might have gone for the former, expecting a low level of demand. After some time, the firm may realize that the product is quite successful, and it would therefore be advisable to reverse the original decision. Similarly, designers unsure of the reliability of a part might have originally chosen a costly and high-resistance material from a very reputable supplier. Experience gained in the field might later suggest going for a cheaper solution.

When tackling phase 1 of VA, the time spent on analysis, brainstorming, checking the viability of the solutions and deciding on them can be quite substantial (consider that, considering current labor rates, a 1-hour discussion carried out by a group of 10 people on a single component can cost around 1000 €). Therefore, it will be worthwhile to engage in such an activity only if the expected benefits—given by unit percentage savings, multiplied by unit cost and volume—are worthwhile. It comes as a consequence that VA should be carried out in the case of products whose volume—or whose unit value—are high enough to justify the effort. Moreover, Bills of Materials are usually characterized by a Pareto distribution, with a minority of components being responsible for the majority of total cost. Hence, the analysis can be carried out for the higher-value components of the BoM only, and neglecting the rest.

The application of this phase of VA to the case of services is quite straightforward, since it consists in making a systematic analysis of process steps, instead of the Bill of Materials.

### *16.5.2 Phase 2—Obtaining the Same Functions at a Lower Cost*

Phase 2 of VA involves a slightly deeper redesign of the product. The overall functions of the product will not be changed, and neither will its architecture. Components are to be analyzed one by one, with the aim of substituting them with "functional equivalents", i.e., different and cheaper components that may deliver the same low-level functions. Referring to the discussions in Chap. 15, this implies changing embodiment choices made at the lower echelons of the function tree. As an example, a mechanical fastener connecting two components could be substituted with adhesive bonding, while an electromechanical relay could be substituted by a low-cost electronic solid-state relay.

The discussions that can be carried out in phase 2 of VA are typically quite narrower than the ones in phase 1, since not all components are actually amenable to substitution, and the range of options available is typically quite small. In order to stimulate the discussion, the VA team can try comparing the actual cost of a component to its theoretical minimum value, i.e., the lowest-cost alternative embodiment, without considering its actual applicability. For instance, a $0.50 spring latch having the function of joining X and Y may be compared to the $0.01 value of a drop of glue. Even if using adhesives is not viable, since X and Y might have to be separated at some point in the product lifecycle, this huge value difference could lead the team to debate on whether separation of X and Y is really an issue and how often it occurs and —in the end—the team might decide for a $0.05 bolt.

Because of the relatively limited range of redesign opportunities, this second phase of VA usually does not last for a long time, since teams will focus on the few higher-value components that can actually be substituted with functional equivalents. However, it would be a mistake to skip this phase altogether, since it usually provides a good baseline understanding of the product and its functional structure, which can be useful when engaging in the subsequent phase 3.

### *16.5.3 Phase 3—Obtaining the Required Functions at a Low Cost*

This third phase of VA (which is usually called Value Engineering) involves a substantial redesign of the product, and is therefore suitably carried out during the initial product development process, rather than for redesigning an already launched product.

The main idea behind Value Engineering is that customers are not interested in the embodiment of the product and of its components (which determines product cost) but in the functions that these components deliver (which determines the product's utility and value). So, if one focuses on functions, each function will "natively" be characterized by a degree of utility (which matters to the customer), while its embodiment will be characterized by cost (which instead matters to the producer). Conversely, if one focuses on components, each will be characterized by cost, but can be associated to the function it delivers, which is instead characterized by utility. So, by translating between the two spaces of functions (and associated utility) and components (and associated costs) the product development team may be able to study and compare cost and utility of both functions and components.

The starting point of this analysis consists in drafting a function tree and comparing it to the bottom tier of the Bill of Materials (as shown in Chap. 15). The utility of functions is usually computed in two steps (Fig. 16.12). At first, relative utilities are computed, assigning a [0, 1] value to each function, which expresses the degree with which that function is necessary in order to fulfill the corresponding higher-level function (in Fig. 16.12, these values are placed in the boxes).

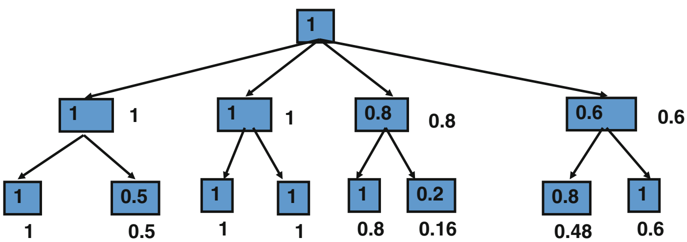



**Fig. 16.12** Computing utility of functions in value engineering

Conventionally, the top-level function is given a value of 1. Then, absolute utilities are computed, by progressing top-down, and multiplying the relative utility of each function by the absolute utility of the function that is placed immediately at a higher-level[2] (in Fig. 16.12, these values are placed next to the boxes).

After having defined utility levels for the lower-level functions, $U_i$, it is possible to compute their cost $\mathrm{CF}_i$ by associating them to the cost $cc_j$ of the components that fulfill them. In the case of modular (i.e., 1:1) relationships the task is trivial, while it is less so in case of more complex architectures. In this case, one will have

$$\mathrm{CF}_i = \sum_j cc_j cf_{ij} \tag{16.6}$$

where $cf_{ij}$ is the share of the cost of component j that fulfils function $i$. In first approximation, $cf_{ij}$ can be computed as $1/k$, $k$ being the number of functions to which $i$ contributes. This computation is often misleading, since components usually are designed around a main function, and are then modified to fulfill additional ones. For instance, the casing of a consumer electronics product may have the main function of "containing other components", with the added function of "providing shock-protection" to the product. In these cases, a better estimation would be made by determining the cost of the main function as the cost that the component would have if it only had to fulfill that function. Then, the cost of the other function would be computed as the additional cost that has to be incurred because of function sharing (for instance, the use of a different material in order to improve shock absorption).

Conversely, it is possible to compute the utility of each component, UC$j$ as in (16.7):

$$\mathrm{UC}_j = \sum_i uf_i fc_{ij} \tag{16.7}$$

where $uf_i$ is the utility of function $i$ and $fc_{ij}$ is the contribution given by component $j$ to function $i$ on a [0, 1] interval.

Having performed these calculations, the VA team will be able to generate the maps of utility and cost for both functions and components (Fig. 16.13). Elements with low cost and high utility will of course be kept and considered as benchmarks. On the opposite side, elements characterized by high cost and low utility will be subject to intense debate and considered as interesting candidates for being pruned away. Expensive and high-utility elements will be kept, but the team will dedicate

[2]The evaluation of utility can be performed either by taking into account purely technical criteria (i.e., "*the degree with which function F2.1 is necessary to fulfill F2*") or a mixture of technical issues and user preferences (i.e., "*the degree with which the customer wants function F2.1 in order to achieve function F2*").

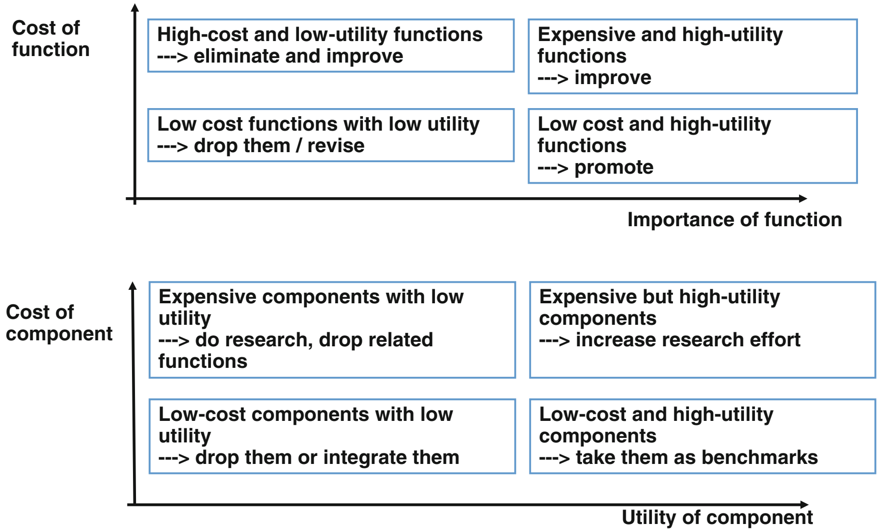



**Fig. 16.13** Mapping functions and components in value engineering

some time in order to find solutions for further cost reductions. Finally, low-cost and low-utility elements will be left alone, dropped, or subject to integration and function sharing in order to squeeze some more costs out of the system.

### *16.5.4 Phase 4—Extending the Results Horizontally*

As previously mentioned, applying VA to a single product often requires spending significant time and effort, which can easily amount to more than the potential benefits, given the unit savings and the production volume of that product. This would limit the applicability of VA. However, many firms offer a very broad catalogue of relatively similar and simple products. In such cases, the ideas coming from a "vertical" VA activity performed on a single product can be easily—and without any additional effort—"horizontally" extended to all the products in the same family. Moreover, ideas that might have not been applicable if applied to a single product may turn out to be interesting if they were applied to all the products in the family.

Based on these considerations, Phase 4 of VA consists in revising the proposals that have arisen in the first three phases of VA for a single product, and studying their applicability to all similar products in the company's assortment. A firm following this approach may therefore continuously alternate vertical and horizontal actions of VA. This approach to VA can be extremely beneficial because it can become an established and efficient routine, at the same time creating a diffuse "culture" of value creation throughout the organization.

## 16.6 Variety Reduction

In many cases, the redesign of products and their architecture has the primary aim of reducing excessive variety in the product range. Many manufacturers witness a proliferation of product variants, components and processes that is relatively unjustified and certainly quite costly. Variety Reduction Programs (or VRP in short) are methods aimed at managing and reducing this phenomenon.[3]

Excessive variety is usually due to lack of communication and the tendency to adopt solutions that are "locally optimal", rather than searching for solutions that are better for the organization as a whole. In general, variety is due to both commercial and technical reasons.

Concerning the former, marketing and sales usually try to segment the market as finely as possible and push the product development process to closely match the needs of each segment, if not of each individual consumer. This tendency can certainly be advantageous by making the product more attractive and allowing the firm to increase sales and/or margins. However, it is obvious that excessive customization can lead to disproportionate and quite costly degree of variety. This is often compounded by strategic mistakes made by the company in setting its Customer Order Decoupling Point, which should never be placed after this variety is generated.[4]

Concerning technical reasons, designers often tend to pursue a high level of perfectionism, therefore looking for the "perfect" component to fit a given function or performance level, thus disregarding the possibility of using a common component that would still perform satisfactorily. This tendency to "over-engineer" is partly psychological, and partly due to uncertainty over the future behavior of the product. Moreover, designers are seldom given tools, such as component databases, that could support the "carryover" of currently used components to new products. Quite often, they may be provided with tools that create an even greater variety (e.g., a spreadsheet algorithm that automates the design of a simple component, but does not check whether the outcome is a close match to an existing part number).

[3]Some authors (Kodate and Suzue 1990) consider VRP to be an antagonist method to Value Analysis, since they assume that VA's efforts to cost-optimize individual products can easily lead to technical solutions that are highly product-specific. As we have seen above, this is not really true, since a proper use of VA should generally take both individual products and the entire product range into account, by alternating vertical and horizontal analysis. So, we can consider VRP to be a useful complement to VA and—at the most—a way for correcting an improper use of this latter technique.

[4]For instance, if customers want products with many different types of decor, the firm should stock unpainted goods and add decorations only after individual orders have come in (or, as in the case of smartphone covers, make it easy for customers to add their own decoration). Similarly, variety in high-end car manufacturing is due to the addition of a high number of combinations of options. So, car manufacturers tend to adopt Assemble-To-Order strategies in which they stock the main subsystems and then assemble each car to order.

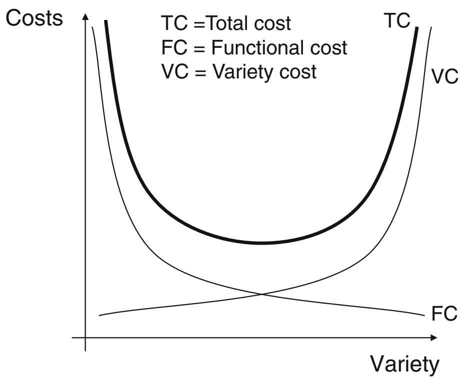



**Fig. 16.14** Costs of variety

Variety can lead to both advantages and disadvantages, thus generating a U-shaped curve, as is qualitatively sketched in Fig. 16.14. Advantages are associated to a tighter fit with user needs (and therefore value) of the product. Disadvantages are instead due to lower returns on investment made on component-specific assets (e.g., a same die will support smaller production runs) and because it forfeits the possibility of looking for production techniques that may exploit economies of scale. In addition, variety will add to organizational complexity and will therefore have multiple impacts on the cost of logistics, information processing, supplier management, and so on.[5]

The problem with variety management is that the curve that is shown in Fig. 16.14 is only qualitative, and it is impossible to compute for a given firm. Therefore, managers will have to act, basing themselves on qualitative measures.

One first and easy step will be to realize whether the firm is located on the left-hand side of the optimum and should therefore increase variety or (far more likely) whether it is on the right-hand side and reduce it. Then, qualitative indicators for variety can be introduced with the objective driving them down to a given threshold. For instance, a "bought component variety indicator" could be introduced by multiplying the number of externally sourced components, times the number of suppliers, times the number of countries from which the suppliers come. A "process variety indicator for internally manufactured components" could be defined as the number of different technological processes used, times the number of different machines per process, times the number of different toolings being used.

Having set objectives, management can then propose and study solutions for variety reduction such as the following:

[5]As a rough guideline coming from inventory management, cost of variety increases with the square root of variety itself. In other words, managing a set of n similar items with demand D costs $\sqrt{n}$ times more than managing a single item with demand nD.

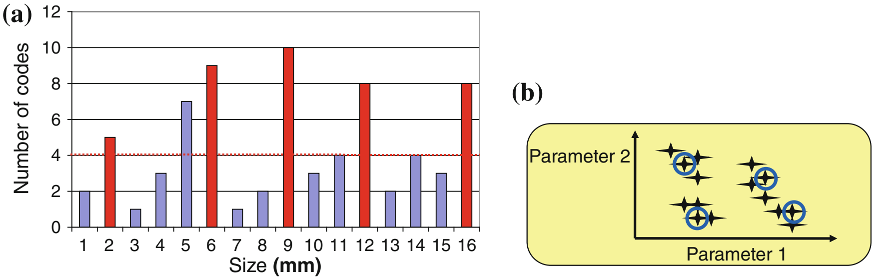



**Fig. 16.15** Using clustering to reduce component variety

- Reducing the number of components by working on their similarity. This task is best performed by using dedicated information system modules, called Component Supplier Management (CSM). These operate on verbal descriptions and physical features of components and—by highlighting similarities—enable the firm to compact their number by defining a limited number of "approved" components. Verbal analysis is carried out by working on spelling mistakes, abbreviations and synonyms. For instance, a component category called "*helical spring*" should incorporate all components described as "*coil spring*", "*coil sprng*", or "*coil sprung*". Then, statistical tools can be used to look for physical similarities on key parameters. In the case of a single parameter, it is possible to use simple histograms. As shown on the left-hand side of Fig. 16.15, the histogram reports the number of product instances that use a component of a given size (alternatively, the number of occurrences could be weighted by the demand of each product using the component). This histogram provides an intuitive indication of which component sizes should be considered as standard (the red bars in the histogram). A firm may then introduce a policy that considers the standard sizes to be "preapproved", so that a designer working on a given application and who has come up with an "ideal" size is nudged into using the closest standard size. In order to provide some more flexibility, non-standard sizes might be used, but only if explicitly authorized by a manager. In the case of components defined by two or more key parameters, a firm may use cluster analysis to highlight groupings of similar components and identify standard ones (right hand side of Fig. 16.15).
- Defining which parts of a product family should be considered to be fixed and common to all members of the family, and which may be product-specific. In a way, this solution is equivalent to defining a product platform strategy.
- Reducing part count by integrating multiple functions in a same component (i.e., function sharing).
- Making an appropriate use of combinatorial variety and revisiting the position of the Customer Order Decoupling Point.

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