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TECHNOLOGY MANAGEMENT

Since technology is such a vital force, the field of technology management has emerged to address the particular ways in which companies should approach the use of technology in business strategies and operations. Technology is inherently difficult to manage because it is constantly changing, often in ways that cannot be predicted. Technology management is the set of policies and practices that leverage technologies to build, maintain, and enhance the competitive advantage of the firm on the basis of proprietary knowledge and know-how.

The U.S. National Research Council in Washington, D.C., defined management of technology (MOT) as linking “engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organization” (National Research Council, 1987). While technology management techniques are themselves important to firm competitiveness, they are most effective when they complement the overall strategic posture adopted by the firm. The strategic management of technology tries to create competitive advantages by incorporating technological opportunities into the corporate strategy.

In the context of a business, technology has a wide range of potential effects on management:

- Reduced costs of operations. For example, Dell Computer Corporation used technology to lower manufacturing and administrative costs, enabling the company to sell computers cheaper than most other vendors.
- New product and new market creation. For example, Sony Corporation pioneered the technology of miniaturization to create a whole new class of portable consumer electronics (such as radios, cassette tape recorders, and CD players).

- Adaptation to changes in scale and format. In the early part of the twenty-first century, companies addressed how small devices such as cell phones, personal digital assistants (PDAs), and MP3 players could practically become, as well as how each product could support various features and functions. For example, cell phones began to support email, web browsing, text messaging, and even picture taking as well as phone calls.
- Improved customer service. The sophisticated package-tracking system developed by Federal Express enables that company to locate a shipment while in transit and report its status to the customer. With the development of the World Wide Web, customers can find the location of their shipments without even talking to a Federal Express employee.
- Reorganized administrative operations. For example, the banking industry has reduced the cost of serving its customers by using technologies such as automated teller machines, toll-free call centers, and the Web. In 2005, the cost of a bank transaction conducted by a human teller was approximately \$2, compared to \$1 for a telephone banking transaction, \$.50–1.00 for an ATM transaction, and about \$.10 for banking over the Internet. Automated Clearing House (ACH) or “checkless” check processing costs were \$.25–.50 per transaction. This reduction in cost could be attributed primarily to reducing the amount of labor involved, which had a profound effect on employment and labor-management relations in banking.

Professor Michael Porter of the Harvard Business School is one of many business analysts who believe that technology is one of the most significant forces affecting business competition. In his book *Competitive Advantage* (1985), Porter noted that technology has the potential to change the structure of existing industries and to create new industries. It is also a great equalizer, undermining the competitive advantages of market leaders and enabling new companies to take leadership away from existing firms. In a Grant Thornton LLP survey conducted during late 2004, 47 of 100 mid-size manufacturing businesses agreed that innovation had become increasingly important to the industry. As M.F. Wolff reported, corporate strategists were encouraging this by bringing product designers along on customer visits, offering rewards and recognition programs to employees with innovative ideas, including innovation as a priority in business strategies, setting revenue goals attributable to innovation, and looking for “willingness and ability to innovate” when making hiring decisions.

It is important to note that technology management is different from research and development (R&D)

management. R&D management refers to the process by which a company runs its research laboratories and other operations for the creation of new technologies. Technology management focuses on the intersection of technology and business, encompassing not only technology creation but also its application, dissemination, and impact. Michael Bigwood suggests that New Technology Exploitation (NTE) lies somewhere between R&D and New Product Development, with characteristics of the cyclical learning process of scientific discovery and the more defined and linear process of product development.

Given these trends, a new professional position, known as the technology manager, emerged. Generalists with many technology-based specializations and new managerial skills, techniques, and ways of thinking, technology managers know company strategy and how technology can be used most effectively to support firm goals and objectives.

Educational programs supporting this career grew as well. Formal Technology Management programs became available in the 1980s and these were largely affiliated with engineering or business schools. Coursework was limited, and the field was just finding its own unique focus. During the 1990s, the increasing integration of technology into overall business function and strategy helped to align technology management more closely with business programs. Most graduate programs in the 2000s were offered through business schools, either as separate MBA tracks or as MBA concentrations. Coursework in these programs shifted emphasis from technology to management, centering around innovation management and technology strategy, while touching on other areas such as operations, new product development, project management, and organizational behavior, among others. There was still little specialization in any particular industry.

During the early 2000s, another shift took place. Global distribution, outsourcing, and large-scale collaboration impacted the nature of technology management (TM) and preparatory educational programs. In response, several MBA programs shifted their technology management focus to “innovation and leadership,” with particular emphasis on real-world problem solving in partnership with large corporations.

TECHNOLOGY AND INNOVATION

Technological change is a combination of two activities—*invention* and *innovation*. Invention is the development of a new idea that has useful applications. Innovation is a more complex term, referring to how an invention is brought into commercial usage. The distinction between the two is very important. As an example, Henry Ford did not invent the automobile; companies in Europe such as Daimler were producing cars well before Ford founded his company. Henry Ford instead focused on the innova-

tion of automobiles, creating a method (mass production) by which cars could be manufactured and distributed cheaply to a large number of customers. However, Ford later failed to innovate further, and lost market share as General Motors began introducing new products and automobile models on a regular basis.

The practice of technology management and the development of technology strategy require an understanding of the different forms of innovation and the features of each form.

- Incremental innovations exploit the potential of established designs, and often reinforce the dominance of established firms. They improve the existing functional capabilities of a technology by means of small-scale improvements in the technology's value, adding attributes such as performance, safety, quality, and cost.
- Generational or next-generation technology innovations are incremental innovations that lead to the creation of a new but not radically different system.
- Radical innovations introduce new concepts that depart significantly from past practices and help create products or processes based on a different set of engineering or scientific principles and often open up entirely new markets and potential applications. They provide new functional capabilities unavailable in previous versions of the product or service. More specifically related to business, radical innovation is defined in a 2005 article by O'Connor and Ayers as “the commercialization of new products and technologies that have strong impact on the market, in terms of offering wholly new benefits, and the firm, in terms of its ability to create new businesses.”
- Architectural innovations serve to extend the radical-incremental classification of innovation and introduce the notion of changes in the way in which the components of a product or system are linked together.

There are two important steps required to properly manage corporate innovation. First is to correctly identify a project as a new product vs. a technological innovation, so a proper development process can be used (the first may be a more traditional stage-gate process; the second should be more cyclical and iterative). Second, managers need to identify what category an innovation falls under, since each type of innovation has its own challenges.

INNOVATION MANAGEMENT

Invention is an activity often identified with a single engineer or scientist working alone in a laboratory until

he or she happens upon an idea that will change the world, like the light bulb. In reality, industrial invention, at least since the time of Edison, has involved many people working together in a collaborative setting to create new technology. Innovation requires an even broader set of people, including manufacturing engineers, marketing and sales managers, investors and financial managers, and business strategists. The methods for organizing this set of people to bring a new idea from the laboratory to the marketplace form the basis of the discipline of innovation management.

Innovation traditionally has been viewed as a linear process, which involves several stages in sequence: research, development, manufacturing, marketing, and ultimately, reaching the customer.

In each step, a group of employees take the idea as it is passed to them from the previous stage, modify it to accomplish a specific function, and pass it on to the next stage. Each team involved in the process has a clear function. Researchers are responsible for creating a working demonstration of the technology, developers and engineers turn it into something that can be produced, manufacturing engineers actually turn out the product, and marketers sell it to customers.

This linear model of innovation has proven to be a misconception of the process, however. For example, problems during the manufacturing process may require researchers to go back and change the technology to facilitate production. The technology may reach the marketing stage, only to turn out to be something no one wants to buy. Technology cannot be handed off between stages like a baton in a relay race. In any case, managing innovation in a sequential process would take a very long time, especially if each stage needs to perfect the technology before it can move on to the next stage. Some models simply add on to the linear stage-gate development approach, adding R&D discovery or planning phases to the front end of the process.

An alternative to the linear model of innovation was offered by the expanded, *chain-linked* model of innovation. This model captures the interactions between the different stages of innovation in a more complete fashion. Some of the important aspects of innovation highlighted by this model are:

- Technologies can move both forwards and backwards in the process, for example going back to the lab if further development is needed.
- Downstream stages (such as marketing) can be consulted for input at earlier stages (such as design and test).
- Scientific research and engineering knowledge contributes to every stage in the innovation process.

- Most firms create technology platforms, which are generic architectures that become the basis for a variety of technology-based products and services.
- The knowledge and skills needed for innovation are developed by communities of practitioners, not by individuals, and many of those communities exist outside of a particular firm (for example, in universities).
- Users of technology can be an important source of ideas for improvements or even new innovations with substantial market potential.

While the chain-linked model of innovation is more difficult to comprehend and analyze than the linear model, it is ultimately more rewarding as it tracks more closely to the way that innovations actually progress on their way from the laboratory to the marketplace.

Another innovation process suggested was new technology exploitation (NTE), as suggested by Bigwood, which resides somewhere between new product development and “pure science.” He defined NTE as “the testing of novel technical approaches specifically aimed at achieving a pre-defined result (target performance, cost reduction, etc.)” It is an iterative process, allowing for the more cyclical learning process of scientific discovery, but clearly working toward tangible goals and benefits.

INTERNAL FORCES AFFECTING INNOVATION

While users and other external organizations are important sources of ideas for innovations, the internal organization of a company has the greatest impact on its capability for creating innovation. The ideal work environment for innovation does not exist. Instead, innovation is facilitated through the tension and balance between various conflicting but necessary forces:

- Creativity and discipline. Creative employees are needed who challenge existing assumptions and develop new and radical approaches to solving key problems. That creativity must be tempered by the discipline to capture the ideas generated by creative employees and by systematically determining which ideas can be turned into innovations, and how.
- Individuality and teamwork. Creativity is considered an individual trait, with some people being more naturally creative than others. But innovation is clearly a team effort, often involving hundreds or thousands of people. While companies should allow employees to express their individuality as a way to facilitate creative thought, that freedom must be placed in the context of the firm as a collaborative environment, where even the most brilliant

individual has to work well with others for the company to succeed.

- **Exploration and focus.** New ideas can come from a wide variety of sources, and it is hard to predict which paths of investigation will lead to the next breakthrough technology. Still, no firm has the resources to conduct research in every conceivable field at all times. The freedom to explore new domains of knowledge needs to be balanced by corporate decisions on what areas of investigation have the greatest promise of paying off, and focusing research in those areas.
- **Long-term and short-term.** Radical innovations often take years to progress from concept to tangible product. For example, the digital computer invented in the 1950s had its roots in research conducted in the mid-nineteenth century on logic and mathematics. Unfortunately, most firms cannot spend money on research that will only begin generating revenues in ten or twenty years. Most innovative activity in firms by necessity is focused on short-term improvements and technologies. Still, firms should not lose sight of long-term innovations, as those are the technologies that can undermine existing market dominance.

One enduring debate in technology and innovation management is whether small firms are inherently more innovative than large ones. The answer appears to be different at different times. For example, the small firm Apple Computer appeared to turn out many more innovations in the 1980s than its large rival, IBM, but in the 1990s, IBM used its huge resources to regain technological dominance in computers while Apple floundered. During the 2000s, Apple came back strongly with innovative designs and technology, such as the iPod and iPhone, and made big waves in the consumer arena.

It may be more accurate to say that small firms are better organized to handle specific types of innovation compared to large firms. Small firms have very streamlined organizational structures that have few layers of management, and managers are multi-functional; i.e., they may handle business development as well as technical work, or they may be project leaders and handle company-wide finances. This cross-disciplinary approach favors flexibility and efficiency, which in turn is more conducive to radical innovation. The small firm model of organization is quite different from large established firms in which personnel in general have more narrow tasks and bureaucratic processes tend to suppress creativity and individual initiative.

Large companies are geared for production and distribution, which are large-scale undertakings that do not

accommodate rapid change. Hence, the organizational structure of a large firm is quite matrix-oriented; engineering disciplines are assigned to projects, and a central laboratory supports research and development. Innovation is organized in a more linear fashion, and internal organization favors discipline and focus. This type of organization is better suited to incremental innovation, since it can identify problems and focus tremendous resources on solving them.

There are several ways in which small and large firms can overcome natural tendencies to gain proficiency in all types of innovation. Lockheed Martin, a large aerospace firm, was the originator of the Skunk Works, a lean, aggressive organization focused on R&D and rapid development of cutting-edge technologies. The group is kept completely isolated from the larger corporate organization, so that the engineers are unencumbered with overhead issues that are handled by other resources within the company at large. From the cultural point of view, aside from the infrastructure, a large company has to handle regulatory matters as well as financial support. A small firm and a Skunk Works of a large firm can be very similar. For example, Xerox's famed Palo Alto Research Center (PARC) also provides an example of how a large corporation can capitalize on advantages that may be more typical to smaller organizations. PARC is owned by Xerox, but is, according to its Web site, an "independent research business." PARC has resulted in the development of numerous Xerox products, as well as the introduction of technologies with wider applications, such as the Graphical User Interface.

A small firm, in turn, can partner with a larger firm to gain access to the resources and infrastructure needed to address incremental as well as radical innovation. Carayannis et al. found that small firms tended to form technology-based strategic alliances as a source of financing. The funds gained through the alliance with a larger firm are then devoted to acquiring and developing tangible strategic assets such as proprietary technology, general working capital, and skills and know-how possessed by key managerial personnel. The large firm in the alliance receives technology-related intellectual property rights (IPRs) and marketing rights more often than equity, manufacturing rights, and so forth, in exchange for their capital infusion. An alliance with a large firm can create a powerful combination that benefits both the small company and its established partner.

During the early 2000s, companies were still seeking ways to build radical innovation competencies into their own organization. O'Connor and Ayers reported on a three-year study of twelve large firms (such as GE, Corning, IBM, and Shell Chemicals, among others) who worked to develop this competency, and identified three key competencies that were critical to success:

Table 1
Technology vs. Market Push and Pull

The Technology Perspective		
	Market Pull	Market Push
Technology Pull	<i>Market Satisfying</i>	<i>Technology Satisfying</i>
Technology Push	<i>Technology Satisfying</i>	<i>Market Seeding</i>

- Discovery—creation, recognition, elaboration, and articulation of opportunities
- Incubation—experimentation, technical, as well as for market learning, market creation, and matching the innovation with company strategy
- Acceleration—exploiting the technology, investing to build new business and infrastructure, responding to market opportunities

Finally, O'Connor and Ayers concluded that no one model works for all companies. Of the twelve companies studied, four had very distinct but different approaches, each influenced by that company's corporate culture. But nearly all participants in the study acknowledged a need for cultural change within the organization before radical innovation could take place.

EXTERNAL FORCES AFFECTING INNOVATION

Various forces outside the direct control of the firm can also affect the innovation process. One set of forces relates to the tension between the demands of the market and the capabilities of the technology under development.

A conventional way of analyzing technology development is to contrast the influence of *technology push* with that of *market pull*. The primary difference between a push or pull scenario is between solving a problem and accommodating a solution. Technology push is the process of solving a problem by providing a technical answer to a market need (which can be either anticipated or existing). Market pull involves solving a problem to provide a market answer to a technical need or accommodating a technical solution by finding market uses. The dynamic balancing act between technology push and market pull drives the speed and acceleration of technological change, and in the process creates significant windows of market opportunity as well as competitive threats to the established technologies.

The terms push and pull can be expanded to encompass either a technology or market point of view:

- Technology push has been historically defined by an innovation-cycle-driven culture focused on marketing/technology management analysis. In this context, a firm's R&D division brings an idea from the invention stage to its fruition in commercial markets.
- The not-so-traditional technology pull is best described as the reaction to demand in the market. The desire for more efficient technologies by customers creates incremental improvements in these technologies that may eventually lead to a critical mass of innovations and possibly to radical improvements.
- On the other hand, market pull has been historically defined by marketing. The marketplace dictates the products that are to be supplied by a firm. In order to meet demand, a firm must constantly strive to increase performance and customer satisfaction.
- Market push is a term that addresses the creation of markets through marketing-driven efforts that, along with technology pull, can lead to the creation of technological standards that define and enable the emergence of new markets (see Figure 1).

Figure 1 presents possible configurations combining market and technology push and pull from a technology and a market perspective. The emphasis swings from a reactive stance, through an accommodating one, to a proactive one (from reacting to demand and satisfying markets to seeding and anticipating demand). The relative strength of each of the four forces (technology push or pull and market push or pull) varies during the lifecycle of the technology.

Technologies, as they develop, often follow a pattern known as the technology S-curve. In the first phase of development, tremendous investment in the technology

yields relatively little improvement in performance, since the investment is devoted to researching various aspects of the technology, many of which do not have useful results. At some point, the technology takes off when a key breakthrough is made. At this critical moment, called an inflection point, the performance of the technology improves rapidly. During this second, or growth, phase, additional investment is focused on the technological breakthrough, with rapid results. As that breakthrough technology is more fully understood and exploited, the rate of improvement begins to slow and the technology enters its third phase, maturity. Finally, the technology reaches a point where additional research yields little new knowledge and few results. At this point, the technology begins the final stage, decline, and often becomes obsolete as better technologies are developed and introduced to the market.

TECHNOLOGY MANAGEMENT AND INNOVATION IN A GLOBAL BUSINESS WORLD

Some have argued that technology management is crucial to a firm's success in the world of globalization. Management scholars have noted that, ironically, the technology and innovation explosion of the late twentieth and early twenty-first centuries has meant that products become outdated at a very fast pace and that consumers have come to expect the rapid introduction and improvement of new technology products. In this environment, companies must achieve a level of synchronicity between R&D and marketing. Otherwise, as the authors of *Strategic Technology Management* stress, problems can arise. Firms may have the correct or necessary new technology product, but fail to market it effectively. Conversely, a marketer can determine a need for a specific new product derived from an environment, but R&D can fail to produce it. This need also highlights the nonlinear nature of product development and technology management. They also note that a business world that is full of change necessitates a degree of long-range planning with technology management.

Globalized R&D Efforts. Others have observed that firms that have highly decentralized multinational operations can face additional challenges. This type of organization can have either their own R&D units in different countries or can have relationships with other organizations, such as companies or universities. R&D is an inherently collaborative endeavor, and because of this, Klaus Brockhoff and John Medcof argue that communication is imperative, especially when different teams collaborating around the world may have cultural and language barriers. However, they also stress that a lot of pointless communication, rather than substantive com-

munication, can make these potential challenges worse. Additionally, there is disagreement with regards to how much autonomy specific research units should have. Some feel that a high degree of control over different R&D units is best, while others see advantages to granting each unit a large measure of independence.

Technology and innovation management constitute a discipline of management that continues to gain importance, impact, and attention. As technology is a pervasive force in business and in society, management of technology helps to ensure that the development of new technology and its applications are aimed at useful purposes, and that the benefits of new technology outweigh the disruptions and difficulties that accompany innovation. While it is possible to specialize in technology management, this discipline also constitutes a set of skills that all managers should possess in the modern technology-intensive and technology-driven world of business.

SEE ALSO *Innovation; Management Information Systems; New Product Development; Organizational Learning; Technology Transfer*

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TECHNOLOGY TRANSFER

According to Carayannis et al., technology transfer usually involves some source of technology, created and owned by a group which possess specialized technical skills; this group then transfers the technology to a target group of receptors who do not possess those specialized technical skills, and who therefore cannot create the tool themselves. In the United States especially, the technology transfer experience has pointed to multiple transfer strategies, two of which are the most significant: (1) the

licensing of intellectual property rights and (2) extending property rights and technical expertise to developing firms.

Technology transfer is a fast-growing activity in the U.S. research and development system, and one which has received substantial attention from governments, industry, and universities. The exact nature of this activity is difficult to pin down, partly because the term has many different connotations. Some of the varieties of technology transfer commonly discussed in business periodicals (such as the *Wall Street Journal*) include:

- International technology transfer: the transfer of technologies developed in one country to firms or other organizations in another country. In the United States, this issue is sometimes associated with the undesired transfer of weapons technology to hostile nations.
- North-South technology transfer: activities for the transfer of technologies from industrial nations (the North) to less-developed countries (the South), usually for the purpose of accelerating economic and industrial development in the poor nations of the world.
- Private technology transfer: the sale or other transfer of a technology from one company to another.
- Public-private technology transfer: the transfer of technology from universities or government laboratories to companies.

While all four types of technology transfer are of concern to businesses, this overview will deal mostly with the first two types. International technology transfer and North-South technology transfer these activities tend to be driven directly by foreign policy and national defense concerns, while the other two types are driven by a balance of corporate and policy interests.

The major categories of technology transfer and commercialization involve the transfer of:

- a. technology codified and embodied in tangible artifacts
- b. processes for implementing technology
- c. knowledge and skills that provide the basis for technology and process development

WHY TRANSFER TECHNOLOGY?

Most technology transfer takes place because the organization in which a technology is developed is different from the organization that brings the technology to market. The process of introducing a technology into the marketplace is called technology commercialization. In many cases, technology commercialization is carried out