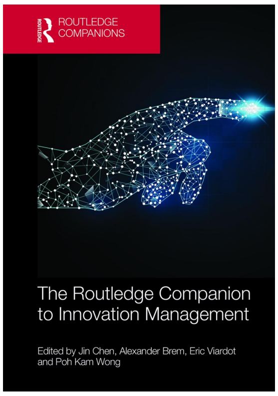

The Routledge Companion to Innovation Management

Jin Chen, Alexander Brem, Eric Viardot, Poh Kam Wong

Technological innovation audit

Publication details
https://test.routledgehandbooks.com/doi/10.4324/9781315276670-25
Xuesong Geng
Published online on: 26 Feb 2019

25

TECHNOLOGICAL INNOVATION AUDIT

Xuesong Geng

As a new concept emerging in recent years, the technological innovation audit (TIA) is borrowed from the financial concept of an audit. In essence, TIA covers but is not limited to the measurement and assessment of technological innovation in every aspect. In this chapter, TIA is examined systemically. The underlying theoretical logics for TIA will be introduced first, followed by the development of a system of indicators for process and performance audit, as well as the metrics designed based on empirical results. Although this section focuses on the analysis of process audit, it is complementary to a performance audit, and the combination of both process audit and performance audit has significant importance for applying TIA to the innovation management of a firm.

Background of TIA

Chiesa, Coughlan, and Voss (1996) described a technological innovation audit as using the innovation audit metrics to examine the current status of innovation management of a firm against the ideal status, identify the problems and issues in need of improvement and collect the necessary empirical information so as to implement the plan to enhance the innovation management. Put differently, TIA can be used to improve innovation management of a firm through the measurement and assessment of innovation activities by firms themselves or third parties. Chiesa, Coughlan, and Voss (1996) pointed out that a technical innovation audit is an important and practical method to improve technological innovation management. TIA has several special features in terms of its theoretical and methodological foundations:

TIA is based on a management audit

Auditing in modern society is an authentication activity carried out by appointed and authorized independent entities or persons on the economic activities of commercial entities. It is highly independent, systematic and authoritarian (i.e. endorsed by governmental bodies). Auditing essentially is a monitoring and evaluating process that provides an evidence-based assessment to ensure the professional and legal compliance of target organization's activities. For example, a finance audit involves the examination and evaluation, as well as necessary corrective suggestions, performed by independent auditors (e.g. accounting firms or certified public accountants) of a firm's accounting reports and financial statements. Besides finance audit, other forms of auditing include production audit, management audit, performance audit and social audit.

A management audit is deemed to be a measure of managerial performance. It encompasses planning, organization, leadership, controls, etc., in many management functions like marketing, production, HR, information system, etc. It is performed primarily through a standardized questionnaire. One of its earlier forms was developed by Jackson Martindell, the founder of the American Institute of Management, back in 1962. The survey consisted of 301 questions on various managerial aspects of a firm, including economic functions, organizational structure, remuneration system, R&D, leadership, production, sales, etc. Notably, it highlighted the fact that effective management can lead to generally good outcomes. Other scholars, such as William Greenwood (1967) and William P. Leonard (1962), also developed management audit questionnaires, laying the groundwork for future research.

A management audit differs from a financial audit in the sense that a financial audit focuses on the end results, whereas a management audit focuses more proactively and forward-looking on processes leading to results. Through a financial audit, the causes are inferred, making it challenging to implement any preemptive measures. Instead, a management audit allows managers to discover loopholes in the management process which can be addressed through the implementation of preventive measures, helping managers achieve organizational goals more effectively. A management audit sets the standards and guidance for effective management.

Benchmarking is the methodological support for TIA

In the modern industrial society, it is nearly impossible for any firm to develop knowledge and R&D all by itself to gain competitive advantages without the use of external knowledge sources and information. The firm must be adept at monitoring and learning advanced technologies from its competitors and integrating them into their own core competencies. As an effective management tool, benchmarking helps firms to achieve this goal. A firm benchmarks itself against the best managerial practices of the most competitive rivals or prominent industry leaders in order to analyze the causes contributing to their outstanding performance and to identify areas for improvement.

MIT and APQC statistics have shown that the vast majority of large American corporations had carried out various benchmarking programs by 1995. Recent research has revealed that benchmarking initiatives have been the main management practice engaged in by the majority of large American companies (collectively accounting for one-fourth of the states' GDP in total) – it is the only management practice that managers in these companies want to continue to strengthen in the future. Xerox Corporation, the original developer of this practice, has seen its productivity increased by 8 to 10 percent since the practice was introduced into its logistics and warehousing sectors. Thirty to fifty percent of this improvement is said to be directly attributed to the benchmarking programs.

A benchmarking program can be divided into five stages. The first stage is the planning stage whereby the firm decides on the relevant departments and specific program components. The key is to find out the core elements contributing to corporate competitiveness. The second stage is to analyze the gaps between the firm and the target benchmarked firms in terms of performance and practice. The third stage is to communicate and share the methodology and philosophy among the employees. The fourth stage is the implementation. The final fifth stage is institutionalization, in which the benchmark program, once proven successful, will be institutionalized as a key activity into organizational routines and procedures. Benchmarking helps the firm to set a credible and practicable goal, making improvement in its competitiveness feasible.

Since the firm always keeps the references to the best-performing firms, benchmarking becomes a dynamic and adaptable process when the external environment changes.

Benchmarking therefore becomes the foundations for the effective management auditing that allows the firm to identify its weaknesses and shortcomings. The quality of benchmarking directly affects the quality and effectiveness of the management audit.

Technological innovation survey provides metrics for TIA

Technological innovation measurement is a critical part of technological innovation management. Measurement is the numerical quantification of a state. Technological innovation measurement uses statistical and empirical data to quantify technological innovation. It involves a comprehensive and systematic analysis of technological innovation activities based on a large amount of empirical data and empirical analysis.

Early innovation research basically revolves around the analysis of factors contributing to success or failure. Examples include a 1969 U.S. research study on 500 innovations across a variety of industries, a 1968 survey by Mansfield on the determinants of American industrial technology changes and a research by Utterback on the successful scientific instrument industry in the United States. In 1976, Lebbenstein studied the purpose of 176 innovations from 13 American companies. Lastly, Project SAPPHO by the University of Sussex, after studying about 40 cases, found six fundamental features of successful innovation.

The corporate innovation survey was first introduced by Germany in 1979 as an annual undertaking. From 1979 to 1989, the technological innovation survey diffused to Canada, the United States, France, the UK, Spain, Italy, Finland, Norway, Sweden and Australia. Among them, the surveys made by Germany and Italy were the most influential.

The Oslo Manual, compiled by the OECD and published in 1992, is the official technological innovation measurement indicator system. It collects the innovation survey experience of OECD countries, and has become the basic guideline for the collection and analysis of technological innovation data. In 1993, the EC Harmonized Innovation Survey 1992/1993 was compiled based on the Oslo Manual. In 1995, 16 Italian manufacturers were chosen for an interview survey and to advise on the Oslo Manual amendment. As new developments of the technological innovation measurement initiative, the OECD S&T indicators experts proposed an amended version in 1997, which incorporated many indicators that reflected characteristics of technological innovation in a knowledge-based economy.

These technological innovation surveys provide reference standards for the evaluation of the process, behavior and performance of technological innovation. The measurement systems developed and adopted by many governmental and professional authorities have made quantitative measurement and auditing of technological innovation possible.

Overall, TIA is based on the development of a management audit, benchmarking and technological innovation survey. However, it integrates these developments in a more systematic and comprehensive manner.

TIA modeling

In general, technological innovation covers the process from the ideation to the commercialization of a technology, involving various functions of a company over a long period, including R&D, production, marketing, strategy and financing. Technological innovation has very high risk and complexity. One of the most common models used to define technological innovation is the chain model (Figure 25.1), which identifies stages of the innovation process and emphasizes the strong interdependence and links between different stages.

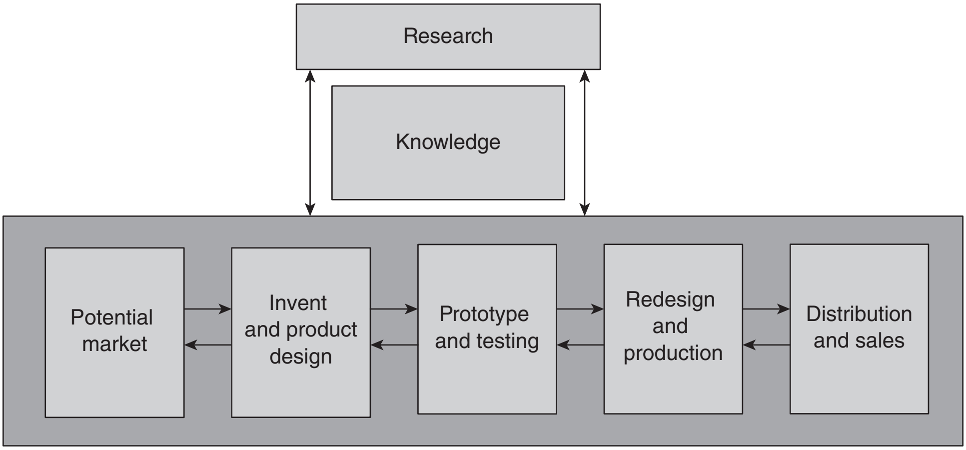

Figure 25.1 The chain model of technological innovation

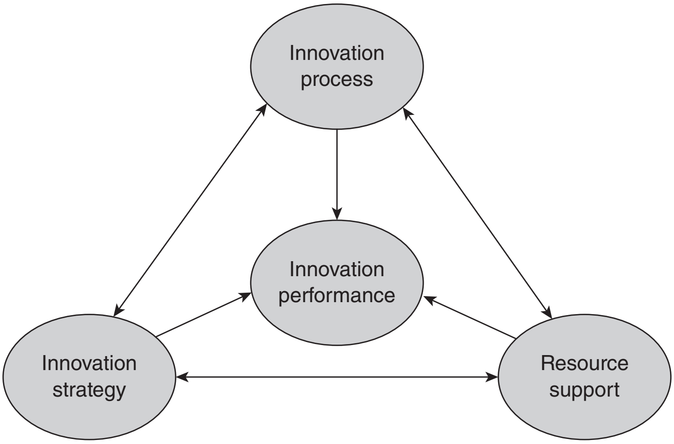

Figure 25.2 The new product performance triangle

The chain model is basically a descriptive model with limitations in practical applications. The model has no clear indication of which links are crucial to innovation performance. In addition, it does not take into account the interplay between technological innovation and other functions in a company such as strategy, structure, culture and HR. With the development of benchmarking, a model of technological innovation success factors has emerged. The model highlights the fact that the outstanding performance of technological innovation is a result of the confluence of five factors: product development process, organizational form, technological strategy, innovation atmosphere and senior management support. Further, based on these five successful drivers, three key organizational factors have been identified as the "new product performance triangle" (see Figure 25.2). The model breaks down the stereotype of a sequential technological innovation model by identifying the key factors for success.

The OECD's Oslo Manual for technological innovation uses the characteristics of technological innovation to divide the basic innovation process into several aspects, as shown in Figure 25.3.

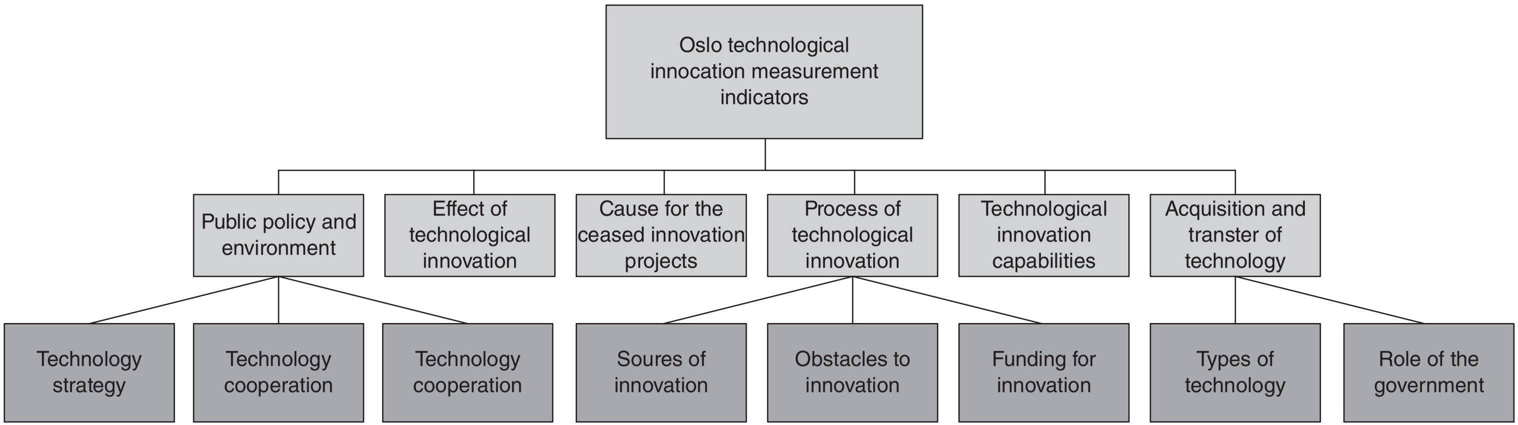

Figure 25.3 Technological innovation measurement indicator system in the Oslo Manual

Innovation process measurement framework	Input measure	Tangible factor	• R&D investment • Non-R&D input • Equipment level
		Intangible factor	• Innovation goal • Innovation strategy • Source of ideas
	Implementation measure	Success factor	
		Failure factor	
		Interface management	
	Output measure	Quantitative direct output	
		Quantitative indirect output	
		Qualitative direct output	
		Qualitative indirect output	
	Non-phase factor	Obstacles	
		Incentive factor	
		Governmental factor	

Figure 25.4 The stage-based technological innovation process measurement framework

Chinese academia and firms have proposed various theories and approaches regarding the measurement of technological innovation. In terms of applicability, the stage-based technology innovation process measurement model proposed by Professor Gao Jian of Tsinghua University has been influential in the development of the TIA in China. As shown in Figure 25.4, the model takes into account the situation of the Chinese firms.

Combining these different models, we believe the technological innovation process can be analyzed from two perspectives. One perspective is based on the sequential thinking of input, implementation and final output, in accordance with the nature of the technological innovation process itself. The other perspective is to view technological innovation as embedded in the company context, examining its interplay with other corporate functions. Based on these two perspectives, this chapter proposes a new technological innovation audit model as shown in Figure 25.5.

First, this model adopts the systematic and dynamic view of the entire technological innovation process. The model is systematic because it not only reflects the components of technological innovation but also the interplay among these components in the organizational context. The entire system consists of the core processes and the supporting systems. There is a mutually dependent relationship between the core processes and the supporting systems; neither can function optimally without the support of the other. Technological innovation has to be contextualized in a specific corporate environment. As different firms have different corporate cultures and organizational structures, they may form different strategies (including corporate strategy and technology strategy, which can influence each other), in different developmental stages and market environments. The model shows that the organizational internal environment interacts with the core innovation processes through the supporting system, as shown in Figure 25.5.

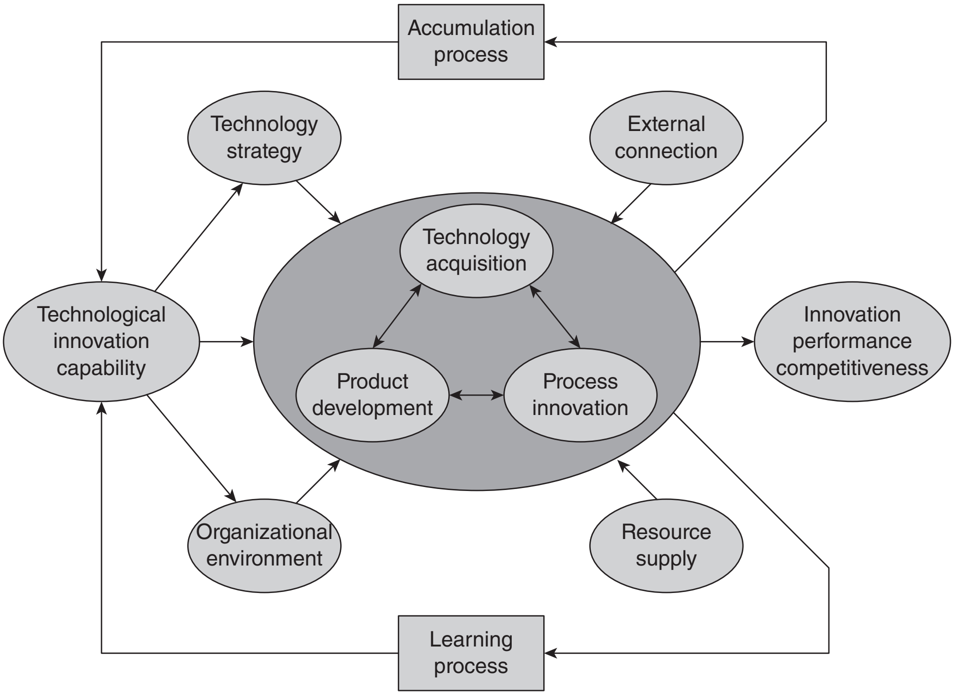

Figure 25.5 The TIA theoretical model

In addition, the model reflects the complex interaction between various components. In the core processes, there are interactions between technology acquisition, product development and process innovation. For example, successful technology acquisition can improve the technological capabilities of the company, which can further promote product development or process innovation. If the company has high product innovation capabilities, it can easily assimilate the external technology knowledge, facilitating technology acquisition. If the company has high capability in process innovation, it can facilitate the acquisition of product innovation as well. The reinforcing effect is also evident between product innovation and process innovation, as suggested by the combinative innovation theory. Second, the supporting system interacts with the core process as mentioned previously. Third, there are interplays among components in the supporting system. For instance, different strategies will directly affect resource supply, and senior managers' support will affect cultural and employee incentives. Moreover, an effective and stable organizational structure is important for the reliability of resource supply.

Moreover, the model reflects the dynamic nature of technology innovation that involves the learning process and path dependence. A learning organization can grow quickly, and its potential resides in the accumulation of knowledge. The difference between firms' creativity can be due to primarily the difference in firms' knowledge stock, which is dependent on firms' learning capabilities. In contrast to tangible resources (e.g. capital, machinery and equipment), intangible resources like knowledge and skills are hard to imitate. Therefore, the difference in technology accumulation can result in a substantial gap in resource possession between firms. As a result, sufficient technology accumulation helps the firm gain an advantage in the race for technological innovation. Knowledge and skill accumulation underlies each step of a technological innovation process, which, conversely, forms a supportive environment for technology accumulation.

Learning and accumulation enable the firm to improve on its technological and innovation capability. This is the heart of sustainable corporate technological innovation.

Another feature of the model is its easy implementation that facilitates senior managers to assign responsibilities to different departments of the firm and conduct management audits effectively. The strategy department can be responsible for strategy matters, the HR or logistics departments for resource supply and the technical or internal auditing department for performance assessment.

Based on the TIA theoretical framework, the firm needs to develop the specific TIA indicator system as illustrated in the following sections. TIA evaluates not only the innovation performance but also the entire process of the technological innovation. A process audit reviews whether fundamental technological innovation processes are being carried out and how optimal implementation plans are being performed, whereas a performance audit reviews the achievements of the various innovation processes and their impact on the firm's market competitiveness.

Process audit of technological innovation

The process audit of technological innovation encompasses the systematic analysis of primarily the core process, supporting system and technological capability accumulation, as well as the corresponding indicator system.

Core process

The core process encompasses primarily technology acquisition, product development and process innovation.

Technology acquisition

The technology acquisition audit focuses on the effective external connections, reasonable technology acquisition strategy and implementation of acquisition.

To acquire technology effectively, a firm must establish broad and reliable external connections, which include other firms (whether competitors or noncompetitors), universities, research bodies, the government, etc. External connections lay the foundation for an innovation network which, as one of the main sources of technology acquisition, links upstream product/equipment suppliers and downstream wholesalers and users, thereby expanding the external connections for technological innovation. External connections are believed to facilitate the technology acquisition to improve technology capability. Besides, the innovation network requires the firm to maintain close relations with the external connections that can only built up over a long time. A firm with an innovation network can acquire or transfer technology in the network with greater ease, thanks to the trust it maintains with long-time partners, hence reducing transaction costs significantly. Therefore, a broad network of connections is indispensable to successful technology acquisition. External connections normally go through key employees, like technology gatekeepers and project managers. Such close personal relationships form an indispensable part of a firm's external connections.

Technology acquisition can be accomplished in many forms, including technology rental, license, cooperation, strategic partnership and joint venture. An appropriate technology acquisition strategy must consider multiple factors such as technology trends, technological features and corporate conditions, as well as their impact on the firm's core capabilities. It is also important to systematically monitor the technology trends by identifying upcoming new technology, acquiring technology information, monitoring competitors and examining internal technology capabilities to determine the best avenue for technology acquisition.

Product development

The product development process refers to the identification of consumer demand, the development of new products using the existing technology or the improvement of the existing product line to meet such demand. Primarily, it encompasses three parts: innovative idea generation (i.e. identification of consumer demand to generate new ideas); product innovation planning (i.e. drafting of product innovation strategy, scope and level of the innovation, and the timeline to commercialization); and product innovation (i.e. the entire process of a product development from planning, to prototyping, to production, and finally to sales and distribution).

In product development, the first activity is the identification of the source of innovative ideas. The source of innovation is not limited only to technical workers but can be from consumers and suppliers as well. As successful innovations are invariably those that can meet consumer demand the best, the role of the consumers or end users is essential. The key is to examine to what extent market demand and new opportunities can be discovered, especially from those departments (e.g. sales, service, etc.) that deal directly with the consumer, and to what extent the creative customers can be identified and how their roles can be integrated in the development, testing and improvement of new products. The end user as the source of innovation ideas serves a dual role. First, as the user of an innovation, he or she is the ultimate motivation for innovation. Second, the end user can guide and assist the product innovation by getting involved in ideation and new product development. A survey shows that user-driven innovations are important in many industries in China, such as textile, printing, metal products, electrical equipment manufacturing, electronics and communications equipment, instruments and meters, etc.

Other external sources of innovation include technological breakthroughs, emulation of competitors, government-backed innovation policies, conferences and exhibitions, science and technological literature, patents, licensing and technology assimilation, as well as guidance in the form of laws, regulations and standards.

The second activity is innovation planning. One example is the product innovation scorecard, which is used to detail the target markets, innovation goals and specific action plans. The routinized product innovation planning can help managers to organize and coordinate activities in product innovation. Moreover, innovation planning facilitates the optimal decision-making under limited resources among various market opportunities, innovation levels and market entry timings.

The third activity is innovation itself, during which the new concept materializes into successful products through development, test and production. Product development covers primarily four components: project management, teamwork and organizational structure, conversion of design to production and sales and industrial design.

Process innovation

Process innovation is a critical process due to its impact on product innovation and its role as the direct source of competitive advantages. According to the Oslo Manual, product innovation revolves around products, while process innovation revolves around manufacturing. Process innovation refers to the adoption of new or significantly improved production methods in order to manufacture products or improve productivity that otherwise could not be possible using current production methods. Process innovation primarily has four modules: production strategy, process innovation, new process implementation and sustainable process innovation.

Technological renovation should be paid special consideration in formulating the production strategy in Chinese companies. Technological renovation refers to the replacement of outdated processes and equipment with advanced processes and equipment to increase production efficiency and improve product quality, improving the technological capabilities as a result. Since the majority of its goals are primarily related to the process innovation, technological renovation bears the closest relationship with process innovation in China. In making a technological renovation plan, proactive and preempting consideration should be given to the future technological potential as well as the existing technological capacities and technological base. Technological renovation is as risky as technological innovation, which makes it very important to conduct a scientific assessment.

Special attention must be paid to the relationship between product innovation and process innovation. According to a finding by the MIT Commission on Industrial Productivity, one of main reasons why America lost its competitiveness and economic development momentum in many industries is because American companies focus too much on product innovation but too little on process innovation. In contrast, the economic development accomplished by Japan and Germany is inseparable from their emphasis on the coordinated development in both product innovation and process innovation. This is particularly important for China as well, because for long time, the dominance of product innovation has led to a biased perception that process innovation is only secondary to product innovation.

Effective implementation of innovative processes is a critical component of process innovation. It depends on the use of cross-functional teams, technology supply and the supporting manufacturing and organizational capabilities. A firm has to manage the inherent risk based on the assessment of the complexity of the process.

Sustainable process innovation is reflected in continuous incremental innovations. To promote sustainable innovation, firms can, for example, set up a special task force to identify new opportunities for sustainable innovation to analyze the process control data, consumer feedback and market competition information so as to continuously improve on the existing processes.

Supporting system

A supporting system for technological innovation includes technical strategy, organizational environment, resource supply and effective external connection. The external connection has been discussed previously as a mechanism that ensures the supporting system enables the core process in the technological innovation.

Technology strategy

The technology strategy consists of strategic formulation, strategy content and strategy implementation. The formulation of technology strategy is based on the correct assessment of the organizational environment. A firm must systematically monitor the changes in the market, in the consumer demand and in the evolution of potential markets. It must also monitor the trends of both existing and future technologies. If possible, the firm should monitor and forecast their competitors' technology and competitive advantages.

In monitoring the external environment, the use of technology-market joint analysis is important for the technology strategy. Technology and market influence each other. As shown in Figure 25.6, in different technology-market spaces, firms need to adopt different innovation

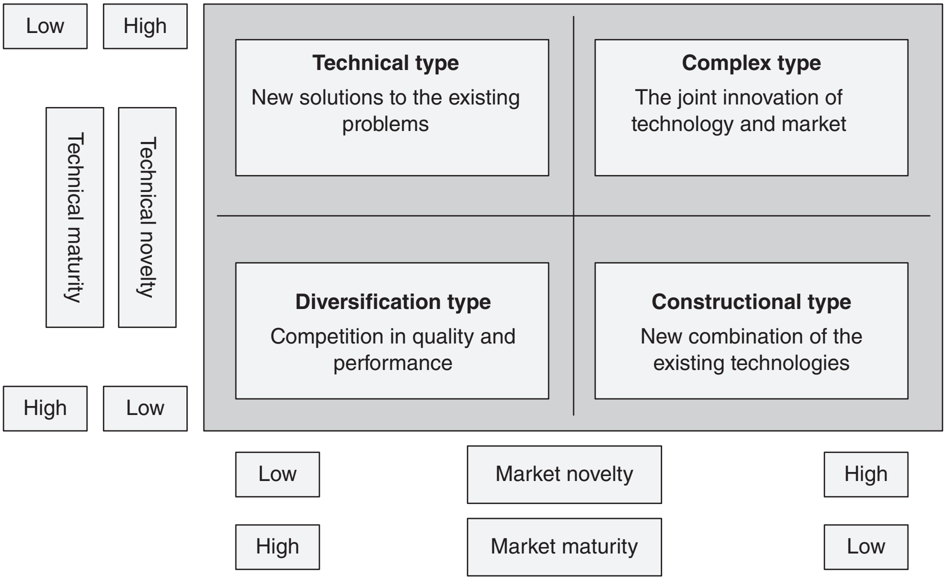

Figure 25.6 The effect of technical and market maturity on technology innovation

strategies. When both the technology and market are mature, the innovation strategy should be designed to improve incrementally based on the existing technology and product platform to meet the needs of users. In performing such a diversification strategy, the traditional market research methods can be effective. Constructive strategy is the new combination of existing technologies. It applies existing technologies to new markets. The driving force for this strategy is customers. The technical strategy is driven by technological developers. It develops and promotes new products according to the needs of users in the existing markets. The complex strategy means that the technology and market are in an uncertain and unpredictable state. For an extremely original or complex one, end users often fail to realize its emergence. Therefore, the firms must develop new technologies and new markets through cooperation between technology developers and leading users.

The formulation of a technology strategy must rely on a firm's own capabilities. The best strategy is the one that can help establish the core competitiveness of a firm. Therefore, in formulating a technology strategy a firm needs to determine the following two issues: first, the positioning of the firm that includes what kind of national innovation system and foreign innovation system it follows, how competitive it is, etc.; and second, the technical development path of the company. Although it is necessary to build the development path on the existing technology, it is important to gradually form some unique core capability that will be difficult for others to imitate.

The technology strategy must satisfy several requirements. It must clearly contribute to the overall corporate strategy. A consensus on the importance of the innovation strategy must be reached within the firm and supported by all its employees. Moreover, the strategy must have emphasis. Also, it must have a long-term goal. Finally, it must effectively satisfy the needs of users and foresee potential future technologies.

Finally, the implementation of the technology strategy must rely on the support of senior leaders as well as the support of employees. Moreover, the firm must strengthen organizational learning capabilities and constantly adapt their organizational forms and management models to a changing environment through benchmarking. The firm needs to formulate appropriate implementation plans based on the corporate strategy and use feedback mechanisms to continuously adjust the existing strategy.

Organizational environment

The organizational environment includes four aspects: top leadership support, cross-functionality, innovation atmosphere and innovation incentives. It examines the internal environment of an organization and the interaction between innovation and other functions.

Top leadership support is one of the key drivers of technological innovation success. The support is reflected in four aspects: top leaders having a great sense of responsibility for technical innovation, assuring the resource supply necessary for technical innovation, playing an important role in decision-making for suspension/continuation of technical innovation projects and providing suitable personnel for technical innovation.

Cross-functionality relies on the integration of technological innovation and other functions, as well as the establishment and operation of cross-functional teams. The impact of cross-functionality is more apparent than that of top leadership support. The SAPPHO Project shows that a major factor in the success of innovation is the functional integration of R&D, manufacturing and marketing. According to a survey on the technical innovation of Chinese manufacturing enterprises, the cooperation between the R&D department and marketing and production is the number two decisive factor to the success of innovation. In order to promote such integration, a cross-functional team is often used in the management of technological innovation projects.

The innovative atmosphere is also a driving force for innovation. A good innovation atmosphere can stimulate employees to create new product ideas, to support spontaneous trial prototyping, to exchange ideas for new products and to adopt pioneering and innovative behaviors. Such an atmosphere can promote the formation of "intrapreneurs". In an innovative organization, individuals with good innovation ability will have the opportunity to fully realize their talent and have the opportunity to put their ideas into practice.

Innovation incentive is an important way to stimulate the enthusiasm and creativity of technical workers by rewarding innovative behavior. There are many ways of incentivizing innovation. One example is the "double career ladder" incentive system that recognizes and promotes the innovative technical employees without necessarily promoting them to management positions.

Resource supply

The resource supply includes the supply of human resources, capital supply and supply of systems and methods.

Human resources are the key resource for successful innovation. The SAPPHO Project states that the senior innovators in a company (so-called technical leaders) are experienced and authoritative, acting as a key to the success of technical innovation. The technical innovation analysis of China's manufacturing enterprises also shows that the technical leaders and senior technicians are important factors.

Capital supply includes financial support for product development, R&D, process innovation, technical renovation and technology acquisition. Funds have been shown to be a bottleneck to many enterprises and one of the reasons for the poor performance of many innovation projects. Therefore, it is particularly important to ensure sufficient funds for technical innovation. The supply of funds requires certain stability (total amount stability) and flexibility (suitable for some short-term projects).

Systems and methods refer to those approaches, systems and methods that support any innovation process. The range of systems and methods is broad. Each firm should establish a set of systems and methods that specifically serve the core process, for example, the communication systems between different functional departments, management methods for efficient product development, management methods for quality control and self-analysis methods for innovation processes.

Technical capacity accumulation

The technical capability of a firm represents the sum of all internal knowledge stocks residing in the personnel, organizations, information and equipment within the firm. The accumulation of technical capabilities will inevitably lead to the improvement of technical innovation, manufacturing, marketing and decision-making capabilities. It relies on the accumulation of technical knowledge stocks and organizational learning. First, technical accumulation is essentially the accumulation of knowledge and experience, specifically residing in the accumulation of individual capabilities. Therefore, a company should ensure stability of a technical team. The key is the stability of the technical leader. After the development and design of a product family are completed, the technical leader should be tasked with similar designs. Second, as the accumulation and improvement of technical capabilities is firm-specific with continuity, it is costly to break the existing technical knowledge structure to re-establish a new knowledge structure. Therefore, the single product development should be expanded to a product family (platform) that is based on the same core technology, making it the most effective way to continuously improve on the product. Finally, a company should pay attention to the accumulation of tacit knowledge. Tacit knowledge is based on the lessons of past successes and failures accumulated over the long period of the innovation process. It is firm-specific and is a valuable asset of the company because it is more difficult to be imitated by other companies. The success rate for innovation is generally about 15 percent. It is unrealistic to expect success without the accumulation of the lessons from failed projects.

Technical accumulation can be achieved through recruitment, training and self-learning of technical personnel; the establishment and improvement of information networks; and the improvement of organizational structure. It can also be achieved through technical cooperation in which different partners can complement each other's technical capabilities. The firm needs to capture the "codifiable knowledge" as well as "sticky information" and tacit knowledge.

The key to improving a company's technical capabilities is to strengthen its learning ability. There are three major learning modes in technical innovation, namely learning by doing, learning by using and learning by R&D. For example, in Chinese enterprises' technology development, employees need the learning by doing when technology imitation is the main task. In this stage, the level of skilled workers is of crucial importance. Learning by using is the dominant model for technical acquisition and assimilation. In independent innovation, learning by R&D is the most important of all. Therefore, different learning mechanisms should be used for different purposes.

Organizational learning is related to personal learning. Blending individual knowledge can facilitate the interaction and recombination of different knowledge, forming new knowledge. In order to allow more knowledge recombination, it is better to have different individuals within a team so as to have different knowledge backgrounds and knowledge structures but also a certain degree of knowledge overlap between them. Different R&D teams can also achieve this interteam learning. The key to successful learning is to establish an effective information exchange mechanism.

Based on the discussion of the technological innovation processes earlier, we propose the audit metric (indicator) system for TIA in Table 25.1. For various indicators, the assessment metrics take the Likert scales 1 to 5.

Table 25.1 Technological innovation process audit metrics

1 Product Innovation
1.1 Innovation Source
* Systematic survey on market demand
* Wide market information network
* Set up departments that respond to customer demands
* Fully utilize feedback from departments that deal with customer demands
* Build long-term relations with consumers, especially core consumers
* Multifunctional perspective assessment on new product design
* Meet market demand through technological improvement

1.2 Product innovation plan
* Integrate product innovation plan into company plan
* Market-oriented planning process
* Prioritize projects in product development
* New product plan portfolio (long-, medium- and short-term plan integrated)
* Selection mechanism for new or improved products
* Plan for idea generation and product innovation
* Centralized control of all processes in new product development

1.3 Independent invention and creation
* Incentive and motivation of employees for product innovation
* Incentive for innovative behaviors
* Support for spontaneous product innovation
* Promote new product innovation
* Organization and structure conducive for independent invention and creation
* Appropriate personnel arrangement for key independent innovation and research

1.4 Product innovation process
* Management of the product development process (from ideation to product)
* Clarity in the scope, phases, milestone, assessment scope, procedure, etc.
* Periodical feedback and improvement in technological development
* Summarization and reflection of completed projects
* Project management system
* Balance the parallel and sequential relations among procedures
* Control the interdependence of projects
* Reduce and control the conflicts among different projects (regarding resource and personnel allocation)
* Set up project process assessment principles
* Set up project priority assessment standard and corresponding measures

1.5 Organization and coordination
* Integrated control and coordination of related functions in the product development
* Make timely communication with other departments and external organizations
* Communicate with varied organizations in product development process
* Utilize cross-functional teams
* Set up project manager–responsible system
* Clear responsibilities and rights of project managers
* Project manager can get support from other functional departments
* Centralized decision making in early phases

1.6 Transition to production
* Coordination among product design, production and sales
* Effective adjustment of development plan (with corresponding system and organization)
* Timely feedback from production to design
* Guarantee in-time delivery through production and design coordination

(*Continued*)

Table 25.1 (Continued)

1.7 Industrial design
- * Integrate industrial design into product development
- * Utilize consulting and advisory teams
- * Set up mechanism to reflect consumer demand in the design
- * Take industrial design into consideration in the beginning of product design

2 Process innovation

2.1 Production strategy
- * Objective assessment on present production capacity
- * Formal procedures for making production plan
- * Set up production capacity to meet the market demand
- * Effective technological renovation procedure and strategy
- * Technological renovation to meet the requirement of products innovation
- * Technological renovation according to international standards
- * Flexibility and adaptability of technological renovation
- * Process innovation promoted by technological renovation

2.2 Process innovation
- * Connect process innovation to product innovation
- * Allocate sufficient resources (human and capital) to develop new process
- * Multiple sources for process innovation (independent, purchased, cooperative)
- * Periodical control and improvement of process innovation

2.3 New process implementation
- * Technological complexity within carrying capacity
- * Effective coordination between production and design
- * Identify the typical process
- * Appropriate adjustment on organizational structure to facilitate process innovation
- * Improve performance assessment standard to better reflect the impact of process on performance

2.4 Sustainable development
- * Proactive process improvement
- * Integrate process improvement and quality control
- * Set up process assessment standard
- * Continuous monitoring after the adoption of new process
- * Have a prototyping process development (or process development backup plan)

3 Technology acquisition

3.1 External connection
- * Senior managers' attention to external connection
- * Maintain a wide external connection
- * Build a long-term and stable relation with suppliers and leading users
- * Build long-term and stable external connection

3.2 Technological acquisition strategy
- * Systematically monitor present and future technology
- * Assess rivals' technological capacity
- * Predict emerging technology
- * Understand the firm's technology capability and competitiveness
- * Set up core competence based on technological capability
- * Integrate technology with business strategy
- * Portfolio of technological acquisition methods
- * Integrate acquired technology to firm's existing technology
- * Set up core competence in technology with the help of external technology

3.3 Technological resource selection
- ⋆ Qualitative and quantitative assessment on technological resources
- ⋆ Has formal procedure for project selection
- ⋆ Time control in project management
- ⋆ Encourage communication and interaction between R&D and other departments

Fully utilize the corporate resource

4 Technical capability accumulation
- ⋆ Monitor the trend in technology development
- ⋆ Allocate resource for preparatory research for future technology
- ⋆ Set up learning organization to accumulate experience
- ⋆ Learn from failed projects
- ⋆ Build formal technological documentation system
- ⋆ Emphasize on improvement on each R&D employee's capability
- ⋆ Embody technological capability improvement in technology strategy

5 Innovation strategy

5.1 Strategy formulation
- ⋆ Monitor market and technology
- ⋆ Market-oriented technological strategy
- ⋆ Organizational structure to ensure innovation strategy formulation
- ⋆ Technology strategy is a key part in the corporate strategy
- ⋆ Technology strategy supports the corporate strategy
- ⋆ Technology strategy aims to improve core competitiveness
- ⋆ Clear assessment and selection mechanism
- ⋆ Use venture investment to enter new field
- ⋆ Assess the impact of innovation on core competitiveness
- ⋆ Utilize all available financial capital

5.2 Strategy characteristics
- ⋆ Specific and clear technological and innovation target
- ⋆ Core competitiveness embodied in technology strategy
- ⋆ The strategy has emphases and phases
- ⋆ Combination of short-, medium- and long-term strategies
- ⋆ Consensus and support of technology strategy in the entire company
- ⋆ Technology strategy supported by specific plans

5.3 Strategy implementation
- ⋆ A specific task force is used to implement the strategy according to the plan
- ⋆ Constant adjustment based on environment and market feedback
- ⋆ Supported by every functional department
- ⋆ Be entrepreneurial in technology strategy formulation and implementation

6 Organizational environment

6.1 Support of top management
- ⋆ Technological innovation is a KPI for senior managers
- ⋆ Proactive management to ensure the effective implementation of technological innovation
- ⋆ Proactive insurance of the sufficient resource for technological innovation
- ⋆ Conduct effective assessment of technological innovation with corresponding award or penalty
- ⋆ Improve the innovation process against the industrial best practices

6.2 Innovation atmosphere
- ⋆ Encourage new idea, risk taking and exploration
- ⋆ Shared understanding of the importance of innovation

(*Continued*)

Table 25.1 (Continued)

⋆ Set up KPI system for innovation performance
⋆ Provide promising career path for technical personnel (dual ladder mechanism, international development, cross-department development)
7 Resource supply
7.1 Human resource
⋆ Have specific human resource expansion plan
⋆ Have long-term plan for future talent accumulation
⋆ Have long-term employee training and recruitment plan
⋆ Human resource support from other departments
⋆ Arrange proper personnel to key positions of technological innovation
7.2 Fund
⋆ Stable capital supply for R&D activities
⋆ R&D investment higher than the industrial average
⋆ Flexibility in allocating funds for process innovation and product innovation
⋆ Reduce risk and cost through cooperation
⋆ Raise funds for technological innovation through multiple channels
7.3 System
⋆ Information system used in product development process
⋆ Information sharing and communication system in innovation
7.4 Methods
⋆ Use new product design methods (CAD, CAM)
⋆ Use other advanced product design methods (roadmap, quick prototyping system, K-J analysis, etc.)
7.5 Quality assurance
⋆ Design quality control (ISO9001, etc.)
⋆ Total quality control in innovation process (TQM)
⋆ Integrate process and product innovation into quality control

Performance audit of technological innovation

The performance audit includes three parts: (1) a firm's overall technological innovation performance, which is mainly according to the OSLO Manual; (2) the performance of each process of technological innovation; and (3) the influence of the innovation process on corporate competitiveness, which is according to Chiesa's auditing questionnaire. The overall performance audit indicators are shown in Table 25.2, the audit indicators of the innovation process are detailed in Table 25.3 and the audit indicators of market competitiveness are shown in Table 25.4.

Applications of TIA

The following several steps are recommended for the application of TIA. The first step is to establish an audit model and framework by an expert panel in the firm. The second step is to use the benchmarking method to determine the indicators. The indicator system should be designed according to the specific strategic goals of the company. The third step is to test and modify the audit model and indicator system. The firm can select the representative department/business unit/project team to conduct the auditing in order to discover the limitations and shortcomings of the original system and to make adjustments. The fourth step is to implement the audit within the entire enterprise. The company can establish an audit task force to carry out the audit in the entire organization. The task force should collect data to analyze the gaps in the technological innovation and propose recommendations for improvement. It is noteworthy that these

Table 25.2 Overall technological innovation performances audit for an enterprise

(A) Main economic indicators
- Industrial gross value
- Profit
- Product sales revenue
- New product revenue/total revenue ratio
- New product profitability

(B) Existing production equipment level

(C) Number of technological innovations

(D) Technological innovation frequency

(E) Innovation investment
- Research and development cost
- Technological acquisition cost
- Technological renovation cost
- R&D intensity

(F) Total R&D fund
- Government funding
- Enterprise self-raised fund
- Bank loan
- Others

Table 25.3 Innovation process performance assessment indicators

Product development

Innovation process efficiency
- Number of new products in the past three years
- Number of renovated products in the past three years
- Number of independently innovated products in the past three years
- Number of projects for new products investment in the past five years
- Number of patents
- Consumer satisfaction (product design that meets consumer need; product scope and type)
- Product plan period (yearly or generation-based products upgrade)
- Average product cycle

Innovation speed:
- Average duration from ideation to product
- Time of each phase (concept generation, design, prototyping, production)
- Average overtime
- Average time for product renovation
- Average time for redesign

Product property:
- Cost (unit cost, production cost, development cost)
- Technical indicators (e.g. usability, operation cost, equipment property)
- Quality

Advantage and disadvantage of design and plan
- Resulted production cost
- Production feasibility
- Test feasibility
- Proportion of redesigned products
- Sustainable development
- Number of innovation proposals per employee
- Ratio of proposals adopted

Improvement in the production level after process innovation
- Quality cost
- Production speed
- Workload
- Reliability
- Technological capacity

Technology acquisition
- Average R&D or technology acquisition cost per each new product
- R&D projects of new products innovation or renovated products, process innovation, licenses and patents (proportion in the overall project and overall cost)
- Number of licenses in the past three years
- Number of cooperation in the past three years
- Profitability of finished R&D project/technology acquisition

Organization and coordination
- Number or proportion of personnel with technological or product development background in the main or secondary departments (branch offices)
- Proportion of employees who can realize and understand innovation policy and value
- Proportion of innovation and technology issues in the annual report

(*Continued*)

Table 25.3 (Continued)

Process innovation	**Resource supply**
• Numbers of new products and significantly renovated products each year • Speed • Installation time (with assurance of no failure in operation) • Development cost	• Proportion of projects delayed or canceled due to fund shortage • R&D investment capacity • Non-R&D investment capacity • Proportion of projects delayed or canceled due to human resource shortage • Personnel qualification and quantity • Proportion of design personnel with training of mass production design • Proportion of team leaders with training in innovation • Proportion of design and drawing personnel using CAD • Number of products based on CAD data

Table 25.4 Performance indicators measuring competitiveness

Types of competitiveness impact	*Measuring indicators*
Single innovation impact on enterprise competitiveness (compared with competitors and/or expectation)	Sales: local market, regional market, international market Market share: local market, regional market, international market
Single innovation impact on enterprise products series	Profit: sales and profit before/after product innovation
Impact of series innovation on enterprise competitiveness	Sales, market share, profit from innovation
Innovation impact on enterprise competitiveness in a certain period	Sales/profit ratio after innovation products introduced three to five years ago Sales/profit ratio after major renovation products introduced three to five years ago

steps are not unidirectional. In the course of implementing the TIA, a company must undergo multiple reiterations and episodes of trial and error to determine the final indicator system. In addition, the company should continuously revise the auditing indicator system to adjust to the ever-changing environment.

Bibliography

Alvarez, H. R. L. and Rune, S. (2001). Adoption of uncertain multi-stage technology projects: a real option approach. *Journal of Mathematical Economics*, 35(1), February, 71–97.

Anschuetz, Ned F. (1996). Evaluating ideas and concepts for new consumer products. *PDMA Handbook*, 195–206.

Arman, M. and Kulatilaka, N. (1999). *Real options: managing strategic investment in an uncertain world*. Boston, MA: Harvard Business School Press.

Bogan, C. E. and English, M. J. (1994). *Benchmarking for best practices: winning through innovation adaptation*. New York: McGraw-Hill Inc.

Burglman, R. A., Kosnik, T. J. and Van Den Poel, M. (1988). Toward an innovative capability audit framework. In Burgelman, Robert A. and Maidique, Modesto A. (Eds.), *Strategic management of technology and innovation*. Homewood, IL: Irwin, pp. 31–44.

Chen, J. (2001). *Eternal and sustainable development*. Beijing: China Science Publishing & Media Ltd. (CSPM).

Chen, J. (2002). *Best innovation company*. Beijing: Tsinghua University Press.

Chen, J. (2004). *Project R&D management*. Beijing: China Machine Press.

Chen, J., Geng, X., and Smith, R, S. (1998). Technical innovation audit: framework and Sino-Canada comparison. *Science Research Management,* (6): 21–28.

Chen, J., (2001). A new exploration on technological innovation information source: leading user research. *China Soft Science*, 2001(1).

Chiesa, V., Coughlan, P. and Voss, C. (1996). Development of a technical innovation audit. *Journal of Product Innovation Management*, 13(2), 105–136.

Chung, K-J. and Ching-Shih, T. (1998). Analysis and algorithm for the optimal investment times of the manufacturing technologies in a Duopoly. *European Journal of Operational Research*, 109(3), 632–645.

Cooper, R. G. (1975). Why new products fail. *Industrial Marketing Management*, (4), 315–326.

Cooper, R. G. (1979). Identifying industrial new product success. *Industrial Marketing Management*, 1979a(8), 136–144.

Cooper, R. G. (1980). New product project: factors in new product success. *European Journal of Marketing*, 14, 277–292.

Cooper, R. G. (1981). An empirical derived new product project selection model. *IEEE Transactions on Engineering Management*, (28), 54–61.

Cooper, R. G. (1988). Predevelopment activities determine new product success. *Industrial Marketing Management*, 1988(18), 237–247.

Cooper, R. G. (1990). Stage-gate systems: a new tool for managing new products. *Business Horizons*, May–June, 45–54.

Cooper, R. G. (1997). Fixing the fuzzy front end of the new product process: building the business case. *CMA-The Management Accounting Magazine*, (8), 21–23.

Cooper, R. G. and Kleinschmidt, E. J. (1987a). New products: what separates winners from losers. *Journal of Product Innovation Management*, 4, 169–184.

Cooper, R. G. and Kleinschmidt, E. J. (1987b). Success factors in product innovation. *Industrial Marketing Management*, 16, 215–223.

Cooper, R. G. and Kleinschmidt, E. J. (1987c). What makes a new product a winner: success Factors at the project level. *R&D Management*, 17, 175–189.

Cooper, R. G. and Kleinschmidt, E. J. (1995a). Benchmarking the firm's critical success factors in new product development. *Journal of Product Innovation Management*, (12), 374–391.

Cooper, R. G. and Kleinschmidt, E. J. (1995b). New product performance: keys to success, profitability & cycle time reduction. *Journal of Marketing Management*, 24, 315–337.

Dai, C. and Li, J. (1996). *Benchmark targeting: new method for enterprises pursuing excellence*. Tianjin: Tianjin People's Publishing House.

Dewar, R. D. and Dutton, J. E. (1984). The adoption of radical and incremental innovation: an empirical analysis. *Management Science*, (30), 682–696.

Dixit, A. and Pindyck, R. (1995). The options approach to capital investment. *Harvard Business Review*, May–June, 105–115.

Dixit, K. A. and Robert, P. S. (1994). *Investment under uncertainty*. Princeton: Princeton University Press.

Eric, von Hippel. (2001). Innovation by user communities: learning from open-source software. *MIT Sloan Management Review*, Summer.

Fan, W., Li, T. and Xiong, G. (2004). *The theory and implementation of products data management* (PDM). Beijing: China Machine Press, 1.

Faulkner, T. W. (1996). Applying options thinking to R&D valuation. *Research Technology Management*, May/June, 39(3), 50–56.

Gao, J. (2005). *Influential elements studies on new product Fuzzy Front End (FFE)*. Zhejiang University.

Galvin, R. (2004). Roadmapping: a practitioner's update. *Technological Forecasting & Social Change*, (71), 101–103.

Gang, G. (2002). *New product digital design and management*. Chongqing: Publishing House of Chongqing University, 3.

Georghiou, L. and Keenan, M. (2004). Toward a typology for evaluating foresight exercises. *Proceedings of New Technology Foresight, Forecasting & Assessment Methods-Seville*, Washington, DC, 15–32.

Greenwood, W.T. (1967). *Business policy: a management audit approach*, New York: The Macmillan Company.
Greg, M. Ajamian and Koen, Peter A. Technology stage-gate: a structured process for managing high-risk new technology projects. www.stevens-tech.edu/cce/NEW/publ.htm.
Griffen, A. and Page, A. L. (1996). PDMA success measurement project: recommended measures for product development success and failure. *Journal of Product Innovation Management*, (13), 478–496.
Groenveld, P. (1997). Roadmapping integrates business and technology. *Research-Technology Management*, 40(5), 48–55.
Gu, Q. (2005). The application of TRIZ in DFSS. *China Quality*, April, 40–42.
Hao, Y. and Jin, C. (1999). Leading user research in technical innovation. *Science Research Management*, 1999(3).
Herath, H. S. B. and Park Chan, S. (1999). Economic analysis of R&D projects: an options approach. *The Engineering Economist*, 44(3), 271–287.
Holmes, C. and Ferrill, M. (2005). The application of operation and technology roadmapping to aid Singaporean SMEs identify and select emerging technologies. *Technological Forecasting & Social Change*, 72, 349–357.
Huang, X., and Wang, Q. (2003). Fundamental theory and practice of TRIZ. *Machinery Design & Manufacture*, 3(5), October, 128–130.
Huiman, J. M. K. (2001). *Technology investment: a game theoretic real options approach*. Boston, MA: Kluwer Academic Publishers.
Jagle, A. J. (1999). Shareholder value, real options, and innovation in technology-intensive companies. *R&D Management*, 29(3), July, 271–287.
Jennings, K. and Westfall, F. (1992). Benchmarking for strategic action. *Journal of Business Strategy*, 13(3), 22–25.
Jian, G. (1997). *An analysis on Chinese enterprise technical innovation*. Beijing: Tsinghua University Press.
Jones, H. and Twiss B. (1984). *Technical prediction used for plan and decision*. Shanghai: Fudan University Press.
Kappel, T. A. (2001). Perspectives on roadmaps: how organizations talk about the future. *Journal of Product Innovation Management*, 18, 39–50.
Keenan, M. (2003). Using expert and stakeholder panels in technology foresight-principles and practice. *Technology Foresight for Organizers*, Ankara, Turkey, F1–F22.
Khurana, A. and Rosenthal, S. R. (1997). Integrating the fuzzy front end of new product development. *Sloan Management Review*, (2), 103–120.
Khurana, A. and Rosenthal, S. R. (1998). Towards holistic "Front Ends" in new product development. *Journal of Product Innovation Management*, (15), 57–75.
Kim, J. and David, W. (2002). Strategic issues in managing innovation's fuzzy front end. *European Journal of Innovation Management*, (5), 27–39.
Koen, P., et al. (2001). Providing clarity and a common language to the 'fuzzy front end'. *Research Technology Management*, March–April, 46–55.
Koen, P., et al. (2002). Fuzzy-front end: effective methods, tools and techniques. Toolbook, 2002.
Koen, Peter, Gideon, M., Robert, B. and Richard, R. (2002). Cognitive skills in the Furry-front end: which ones allow corporate teams to obtain start-up funding? In *PDMA Research Conference Proceedings*, Orlando, 87–108.
Lan, M. (2003). Ten years of UK foresight. *Paper Presented at NISTEP International Conference on Technology Foresight*, Tokyo, Japan.
Lan, M. and Keenan, M. (2003). Overview of methods used in foresight. *Technology Foresight for Organizers*, Ankara, Turkey, E1–E16.
Lee, J. and Dean, P. A. (2001). Valuation of R&D: real American sequential exchange options. *R&D Management*, 45(10), 1359–1377.
Leifer, R., et al. (2000). *Radical innovation: how mature companies can outsmart upstarts*. Boston, MA: Harvard Business School Press, 62–98.
Leonard, W. P. (1962). *The management audit*. Englewood Cliffs, NJ: Prentice-Hall.
Liam, F. and Randall, R. M. (1998). *Learning from the future: competitive foresight scenarios*. New York: John Wiley & Sons Ltd.
Linstone, H. A. (1984). *Multiple perspectives for decision making*. New York: North-Holland.
Lint, O. and Pennings, E. (1998). R&D as an option on market introduction. *R&D Management*, 28(4), 279–287.

Li J. (2002). *Global technique foresight trend*. Shanghai: Shanghai Scientific & Technical Publishers.
Li, J. (2003). Time and thoughts on shanghai's technical foresight. *World Science*, 2003(4).
Li, J. and Dai, C. (1996). *Benchmark targeting*. Tianjin: Tianjin People's Publishing House.
Lynn, G. S., Abel, K. D., Valentine, W. S. and Wright, R. C. (1999) Key factors in increasing speed to market and improving new product success rates. *Industrial Marketing Management*, (28), 319–326.
Lynn, G. S. and Akgun, A. E. (1998). Innovation strategies under uncertainty: a contingency approach for new product development. *Engineering Management Journal*, 1998(10), 11–17.
Management Science School of Shanghai Railway Institute (Ed.) (1985). *Technique development and technique prediction*. Shanghai: Shanghai Jiaotong University Press.
Martin, B. and Johnston, R. (1999). Technology foresight for wiring up the national innovation system. *Technological Forecasting and Social Change*, (60), 37–54.
Martino, J. P. (1993). *Technological forecasting for decision making* (3rd ed.) New York: McGraw-Hill.
Mats, L. and Bandhold, H. (2003). *Scenario planning: the link between future and* strategy. Palgrave.
McGrath, R. G. (2000). Assessing technology projects using real options reasoning. *Research Technology Management*, 43(4), July/August, 35–50.
Michelle Jones, L. and Pitts, Barbara M. (2004). Successfully implementing the stage-gate NPD system. Stage-Gate Inc. Working Paper No., 18.
Mitchell, G. R. and Hamilton, W. F. (1988). Managing R&D as a strategic option. *Research Technology Management*, May/June, 15–22.
Moenaert, R. K., et al. (1995). R&D/marketing communication during the fuzzy front-end. *IEEE Transactions on Engineering Management*, 42(3), S243–S259.
Mu, R. (2003). Beijing's technique foresight: practice and thoughts. *World Science* 2003(4).
O'Connor, P. (1994). Implementing a stage-gate process: a multi-company perspective. *Journal of Product Innovation Management*, 11, 183–200.
OECD Statistical Office of the European Communities (1997). *OSLO manual – proposed guidelines for collecting and interpreting technological innovation data*. OECD/Eurostat.
Panayi, S. and Trigeorgis, L. (1998). Multi-stage real options: the cases of information technology infrastructure and international bank expasion. *The Quarterly Review of Economics and Finance*, 38, Special Issue, 675–692.
Perlitz, M., Thorsten, P. and Randolf, S. (1999). Real option valuation: the new frontier in R&D project evaluation? *R&D Management*, 29(3), 255–269.
Petricka, I. J. and Echols, A. E. (2004). Technology roadmapping in review: a tool for making sustainable new product development decisions. *Technological Forecasting & Social Change*, (71), 81–100.
Phaal, R., Farrukh, C. and Mitchell, R. and Robert, D. (2003). Starting-up roadmapping fast. *Research Technology Management*, March–April, 52–58.
Phaal, R., Farrukh, C. and Probert, D. (2001a). *Technology roadmapping: linking technology resources to business objectives*. Cambridge: University of Cambridge.
Phaal, R., Farrukh, C. and Probert, D. (2001b). *The fast start to technology roadmapping: planning your route to success*. Institute for Manufacturing, Cambridge: University of Cambridge, Mill Lane, ISBN: 1-902546-09-01.
Phaal, R., Farrukh, C. and Probert, D. (2004). Customizing roadmapping. *Research Technology Management*, March–April, 26–37.
Pu, X. (2002). Definition of technique foresight and its relations with technique prediction. *Science & Technology Review*, 2002(7).
Rachel, C. and Wootton, A. B. (1998). Requirements capture: Theory and practice. *Technovation*, 18(8/9), August/September.
Richy, J. M. and Grinnell, M. (2004). Evolution of roadmapping at Motorola. *Research Technology Management*, March–April, 37–41.
Rinne, M. (2004). Technology roadmaps: infrastructure for innovation. *Technological Forecasting & Social Change*, 71, 67–80.
Robert, G. (2000). Cooper, doing it right: winning with new products. *Ivey Business Journal*, July/August.
Robert, G. C. (1994). Third-generation new product processes. *Journal of Product Innovation Management*, 11(3), 14.
Robert, G. Cooper, Edgett, Scott J. and Kleinschmidt, E. J. (2002). Optimizing the stage-Gate process: what best-practice companies do. *Research Technology Management*, September/October, 45, 5.

Robert, G. Cooper and Kleinschmidt, Elko J. (1995). Benchmarking firms' new product performance & practices. *European Management Review*, Fall, 112–120.

Robert, J. T. (1980). Management auditing. AMACOM, a division of American Management Associations, New York.

Russ, M. (2003). Control fuzzy front end. *PM World Today*, Translated by Yan Yongmei, July–August 2003.

Samuelson, N. (1998). translated by Xiao Chen, etc. *Economics* (V16). Beijing: Huaxia Publishing House.

Sandia National Laboratories. Fundamentals of technology roadmapping. www.sandia.gov/Roadmap/home.htm#what02.

Scarso, E. (1996). Timing the adoption of a new technology: an option-based approach. *Management Decision*, 34(3), 41–46.

Science Directorate. (2002). *Defra: Defra's horizon scanning strategy for science*. London: British.

Science and Technology Office of National Bureau of Statistics of China (Ed.) (1993). *A handbook of technical innovation statistics*. Beijing: China Statistics Press.

Shao, J. (2004). *Quality function deployment*. Beijing: China Machine Press, 2004.

Smith, J. E. and Robert, F. N. (1995). Valuing risky projects: option pricing theory and decision analysis. *Management Science*, 41(5), 795–816.

Study Team of Technical Prediction and National Key Technique Choice (2001). *From foresight to choice*. Beijing: Beijing Publishing House.

Sun, Z. (2002). Technique foresight in Japan. *World Science*, 2002(7), 41–42.

Tan, R. (2003). Research progress of several questions on product innovation design. *Chinese Journal of Mechanical Engineering*, 2003(9).

Tong, B., and Li, J. *Product Data Management (PDM) technique*. Beijing: Tsinghua University Press, 11.

von Hippel, E., Thomke, S., and Sonnack, M. (1999). Creating breakthroughs at 3M. *Harvard Bussiness Review*, September–October, 47–57.

von Hippel, E. (2005). *The source of technical innovation*. Translated by Liu Xielin, etc. Beijing: intellectual Property Publishing House.2005.

Walsh, S. T. (2004). Roadmapping a disruptive technology: a case study – the emerging microsystems and top-down nanosystems industry. *Technological Forecasting & Social Change*, (71), 161–185.

Wang, G. (2002). Technique foresight in South Korea. *World Science*, 2002(11), 39–40.

Wang, J. (2003). Computer-facilitated innovation design system tesearch based on TRIZ.

Wang, R. and Mu, R. (2003). From technique prediction to technique foresight: theory and practice. *World Science*, 2003(4).

Wang, Y. and Chen, J. (2002). Research on enterprise core capacity high-standard positioning. *Journal of Industrial Engineering and Engineering Management*, (4).

Xu, L., et al. (1989). Technique foresight on hyper quantum intervene device via Delphi method. *Studies in Science of Science*, January.(Ed.) (1986). *Research and development management*. Beijing: Higher Education Press.

Xu, Q. (Ed.) (2000). *Research, development and technique innovation management*. Beijing: Higher Education Press.

Yanger, C. (赤尾洋二). (1990). *An introduction of quality deployment*. Tokyo: Japanese Science and Technology Press.

Yang, C. (2003). *Real option and its application*. Shanghai: Fudan University Press.

Yang, X., Yang, M. and Lu, X. (2005). Innovative design of home-made cellphone based on TRIZ theory. *Packaging Engineering*, 26(2), 140–141.

Zhang, W., Zhang, G., He, H., et al. (2005). Solution to complicated mechanic and electric products innovation design via TRIZ theory. *Machine Design & Research*, 21(3), 15–18.

Zhang, X. (2002). Start with Chinese Translation of QFD names. *China Quality*.

Zhao, X. (2004). *Technical Innovation Theory (TRIZ) and application*. Beijing: Chemical Industry Press.

Zhang, H, Chen, J. and Gao, J. (2004). Research on fuzzy front end management of radical product innovation. *R&D Management*, 16(6), 48–53.