Strategic planning for management of technology of China's high technology enterprises

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Abstract

Purpose – The objective of this paper is to explore, describe, and explicate the processes which are related to the strategic planning for technology management, and to provide beneficial suggestions for China's high technology enterprises to promote technology management capability.

Design/methodology/approach – In this paper, a model for strategic planning for management of technology is developed, which is expected to be used to provide effective processes of articulating strategic planning. The model involves several key points including defining the current situations of technology management, determining the objectives of managing technology, and designing the approaches for the promotion of technology management capability. Capability maturity model (CMM) and fitness landscape theory are applied in this model to construct useful analysis tools. The model is used to make the strategic planning for management of technology of China's high technology enterprises. A survey of 43 high technology companies in China is conducted. Technology management maturity model (TMMM) is employed to assess the technology management maturity level, and fitness landscape of technology management is developed to explore the routines of promoting technology management capability.

Findings – The authors find that there is still much room for China's high technology enterprises to improve their technology management capability, since the average technology management maturity is only in the managed level. And the maturity of quality management is lower than that of organization management and resource management, and so quality management should have more importance attached to it, promoting holistic technology management capability. All such findings imply that our research makes theoretical contributions to technology management and strategy related literature with significant managerial implications.

Originality/value – The paper contributes to technology management literature by constructing the model of strategic planning for technology management, viewing it as the roadmap of the development of technology management, explaining three interrelated points and illustrating three processes. Second, the paper uses fitness landscape and NK model to explore the routines of promoting technology management capability.

Keywords Technology led strategy, Strategic planning, China

Paper type Research paper

I. Introduction

Over the past 30 years, China's most industries, high-tech industry especially, are undergoing radical transformations due to mega-competition taking place on a global

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scale after her entrance into World Trade Organization (Lukas *et al.*, 2001). And most changes are directly caused by or related to the development, perception and use of technology. Thus, the emphasis of many high technology enterprise initiatives concentrates upon encouraging technology transfer to access new technology (Li-Hua, 2006a, b). A strategy for the development of high technology, the 863 Programme, has also been conducted to promote the progress of high technology and to strengthen technological capability of high technology industry since 1986 by the Chinese government (Lau and Busenitz, 2001). However, studies have shown that the strategy formulation is technology tent in rapid growth high technology enterprise (Lau *et al.*, 2008). Therefore, there is a potential problem in China's high technology enterprises which fail to acknowledge the importance of strategic management of technology, and the critical role of the strategic planning processes in initiating and implementing effective technology management (Zhu, 2008). This is particularly true given that previous researches have identified strategic planning as key areas of weakness within enterprises where the purely technological side of their business is often over-emphasized and other key strategic issues are neglected (Lau *et al.*, 2002; Li-Hua, 2006b). The gap between technology management and technology development in the high tech enterprise has been variously described as an opportunity area, and a root cause of competitive disadvantage. Similarly, the link between strategic planning for technology management and technology strategy has been viewed as a natural concomitant of growing maturity in the high technology enterprise, an integral and necessary evolution in corporate philosophy, and a positive task for an increasingly professional management team (Kurokawa *et al.*, 2005). It is surprising that, despite the perceived importance of high tech enterprises in technological innovation and international competitiveness, very little detailed study has been undertaken into strategic management of technology management in these enterprises.

This paper builds on previous research on strategic planning, and mainly focuses on technology management and the unique circumstances facing China's high technology enterprises which are often founded upon the R&D capabilities. The remainder of this paper is organized as follows. Section 2 clarifies the processes of strategic planning for management of technology, and establishes the model of strategic planning for technology management. In Section 3, technology management maturity model (TMMM) and fitness landscape theory are developed as the tools for strategic planning. Section 4 introduces the research method and Section 5 provides the empirical study of 43 high technology enterprises in China, and some findings are also reported in this section. The last section contains some concluding remarks and managerial implications.

II. The model of strategic planning for technology management

A. The concept of strategic planning for technology management

The concept of strategic planning for technology originates from the description of the reasons for the attributed failure of traditional approaches to technology management which include R&D management school, innovation management school, and technology planning school (Drejer, 1996, 2002). Although it had been recognized that the integration of business and technology was critical to success in the environment of stiff competition, changing social values, and rapid development of new technologies, the strategy principles were not fully applied in traditional technology management, which resulted in the following problems:

- the rate of technology absorption was low;
- the rate of implementation failure was high; and
- the social consequences of new technology were poorly handled.

Further, five factors had been found out to explain the reasons of the three problems discussed above, which revealed that a number of other issues interact with technology and technology management. According to Drejer (1997), the five factors included:

(1) Absence of management attention. Strategic technology management has yet to reach the top management agenda which is much too often focused on business issues.

(2) Absence of organization attention. Organizational issues are ignored which cannot be separated from the implementation of new technology.

(3) Lack of mutual understanding between technology and business. Too often top managers do not fully understand the relations between future products or processes and technology management.

(4) Improper integration between technology and organization.

(5) Lack of strategic appreciation of technology.

The result of the discussion led the scholars to consider the strategic planning issue of technology management, and a new school of technology management theory – strategic school of technology management was developed (Liwarcin and Soyak, 2006). Within this school, management of technology is seen as the practice of integrating technology strategy with business strategy in the company (Chiaromonte, 2003). And it becomes an important strategic instrument to create competitiveness, which still holds the promise of creating prosperity in countries that effectively apply this instrument in the world. Along this line, technology management includes such abilities of creating a mutual understanding between business and technology, recognizing the limitations of strategic business planning process, and incorporating technology as a part of corporate strategic planning process (Edler *et al.*, 2002). Therefore, technology management itself can be regarded as an explicit part of strategic management (Kurokawa *et al.*, 2005; Pandey and Brent, 2008; Burgelman *et al.*, 2008). The formulation of models and frameworks of the enterprise's strategic planning, however, does not mean that the development of technology management can be well planned. In most conditions in China, technology management is only regarded as the tool or the measure that guarantees the implementation of firm strategy (Wu and Xie, 2005). As the capability of planning, developing, and implementing technological capabilities to shape and accomplish the strategic and operational objectives of the enterprise, technology management requires strategic planning to direct and strengthen its development.

Strategic planning is the process of developing a roadmap to achieve a defined set of goals and optimize future potential, which has been recommended as an essential tool for managers (Chen *et al.*, 2009). Strategic planning for technology management is the roadmap to promote the development of technology management. And in details, strategic planning for technology management is the planned or actual co-ordination of major elements and actions, in time and space, which continuously co-align technology management with technological capability, corporate strategy and its environment. This definition encapsulates three interrelated points: element/behavior, co-ordination, and adaptation.

Element/behavior. Strategic planning for technology management means to set development goals and to program elements and activities of technology management in order to promote technology management capability. In practice, the essence of strategic planning is analyzing data and information of elements of technology management to formulate a structural development plan (Burgelman *et al.*, 2008). These data and information are mainly concerned with the behaviors of technology management elements. These elements can be concluded into three categories – resource (including terms of human resource, fund, equipment, information, and technological result), organization (including terms of organizational structure and culture), and quality (including terms of technological quality, standardization, and technological risk) (Yu *et al.*, 2003). Thus, the main content of strategic planning for technology management is to confirm the importance of these elements and in nature, strategic planning is the permutation and combination of different functions of technology management.

Each element requires integrating key actions including searching, selecting, and implementing (Bowonder and Miyake, 2000). Searching means monitoring what is going on and searching information of inside and outside environment. Selecting refers to picking up and categorizing key signals as early as possible and making action plans. Implementing refers to carrying out plans and taking measures to adapt to changes of environment (Wu *et al.*, 2009).

Coordination. The elements of technology management are closely related to and interacted with each other dynamically. The relationship between them is non-linear, which strengthens the complexity of technology management system (Miyazaki and Kijima, 2000; Gaimon, 2008). Changes of one element will greatly affect conditions of the other two. If the three elements are well coordinated with each other, the negative entropy of technology management system will increase, which indicates that the order of technology management system is increased (Christodoulou *et al.*, 2009). Therefore, the coordination of these elements will exert great influences on the efficiency of technology management, and it should be the principle of making the strategic planning.

Adaptation. Technology management was ever seen as a mediating force between the overall process of technological change and the internal structuring of technological activities within the organization, taking the perception that the business environment is simple and predictable in terms of technologies and technological performance (Liao, 2005). Thus, technology management is seen as something which can be rationally planned by analyzing S-curves, forecasting technological performance and investing in R&D (Miyazaki and Kijima, 2000). The environment, however, is now regarded as highly complex and focuses on the instability of technological change, short life cycles and varying customer demands (Pilkington and Teichert, 2006). In this condition, technology management should not only take issues inside companies into account but also focus on the adaptation to their environment (Bessant and Francis, 2005). Proactive and effective strategic planning makes technology management generate quick responses to environmental changes and further become the source of high performance. In this sense, the main task of strategic planning is just to make technology management system adapt to the environment.

B. Processes for strategic planning for technology management

Strategic planning begins with the creation of a gap between the current reality and an image of an aspiring future, and focuses specifically around a view of planning that fosters adaptability (Liedtka, 2008). Strategic planning for technology management distinguishes between two distinct but interrelated aspects – one cognitive and one behavioral. At the cognitive level, the strategic planning process finds ways to identify current conditions and utilizes strategic thinking to set goals. At a behavioral level, designs for achieving goals are made and are realized as the organization "programs" them into the development of new routines and capabilities aimed at achieving the kinds of outcomes that the ideal future envisions.

Strategic planning for technology management involves three processes: identifying current conditions, setting development goals, and designing the development routine.

Identifying current conditions. It is the first step to make strategic planning, which involves assessing the capability of each element and the overall capability of technology management. And the identifying process is also primary because only if an organization understands its own conditions, can it put forward helpful procedures and methods to manage technology. Thus, an effective method for the assessment is required to confirm the level of technology management capability and to provide guidance for capacity improvement.

Identifying key technological activities and problems in technology management activities is an important task in this process. All behaviors of technology management elements should be taken into consideration, and by benchmarking managers can find out problems in management of technology, and provide directions for improving technology management capability.

Setting development goals. The ultimate goal of strategic planning for technology management is to gain adaptation to the environment and further to gain performance and competitive advantage (Dittrich and Duysters, 2007). This ultimate goal, however, is achieved step by step, which indicates the adaptive evolution of technology management system. Thus, the goal of each step should be set to ensure that technology management capability develops towards the right direction. Each goal is essentially a certain combination of capabilities of technology management elements. The goals, whether the ultimate one or each step's, are all performance oriented, which means in each step the best performance the element combination can achieve should be acquired.

Designing the development routine. Design is defined as a "shaping process," a "reflective conversation with a situation" in which "each move is a local experiment which contributes to the global experiment of reframing the problem" (Schon, 1983). Planning's ability to foster the exploration of routines of development is one of the sources of its value to organizations. In each step, we argue that only one element should be improved because of the non-linear relationship among all elements and behaviors. The non-linear relationship will result in the complexity of technology management system and decide the managerial entropy (Liu and Jiang, 2003). In this condition, if the three elements are regulated at the same time, their interaction and feedback will increase the communication or information in large quantities, which will further result in the consuming and reducing of the efficiency of technology management. Besides, the complexity that simultaneous regulations bring about will make the regulations cannot be controlled easily and result in the instability of technology management system.

Thus, designing the routine is to find out the order of the improvement of technology management elements.

C. The model of strategic planning for technology management

Taken together, a model for strategic planning for technology management, comprising two levels and three steps, can be established which is shown in Figure 1.

In this model, the gap between "today's reality" and "tomorrow's intent" is the impetus of making strategic planning. In the absence of such a gap, and the cognitive dissonance that it creates, there exists no internal motivation to change, as change theorists have long pointed out (Liedtka, 2000). And as conceived by this model, the process is continuously in motion, as the gap is broadened, and subsequently narrowed, through the interaction of the new objectives that the organization sets and the new capabilities that it develops.

III. Tools for strategic planning for technology management

A. Technology management maturity model

In order to make assessment of current conditions of technology management, we develop the TMMM, since the term maturity might be used as an indication or a measurement of enterprises' technology management capability (Wang *et al.*, 2007). Maturity is the quality or state of being mature, and when it is applied to technology management, the term technology management maturity refers to the effectiveness and perfection degree for an organization to identify, develop, manage, and control its technological capability, which can explain "today's reality" of technology management.

(1) The structure of TMMM. Technological capability is closely related to technological elements. And technology management is just an activity of managing these elements. Technology is originally seen as man's tools, which involves not only machines, computers and robotics, but also the methods and techniques. Now the view of technology has evolved into a very complex perception in which technology is seen in relation to people, organization, processes, information and so on (Chul, 1998). According to Asia and Pacific center for technology transfer, technology includes such elements as technoware, humanware, inforware and orgaware. Technoware refers to machines, equipments and tools that are used. Humanware refers to the abilities and

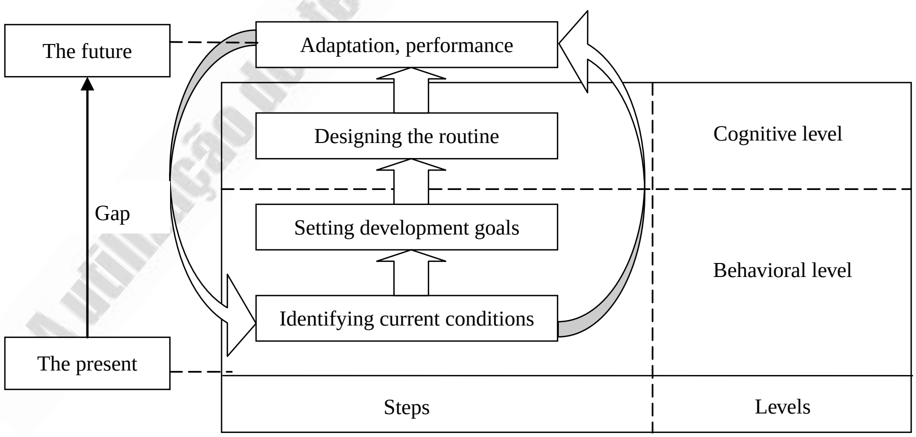

Figure 1. The model of strategic planning for technology management

skills of human that operate machines and produce products. Inforware are the documents and information that are needed in production. And orgaware refers to organization structure. In technology management, we adopt a broader view and hold this opinion that elements of technology include human resource, fund, equipment, information, technological result, organizational structure, culture, quality, standardization, and technological risk. These elements can be concluded into three categories: resource (including human resource, fund, equipment, information and technological result), organization (including organizational structure and culture), and quality (including technological quality, standardization and technological risk). Thus, technology management maturity itself is the result of managing the three categories of elements, and it can be measured along three dimensions: resource management, organization management and quality management. Each dimension's maturity reflects the management condition of elements it includes. The maturity of the three dimensions indicates the overall condition of technology management.

Figure 2 shows the structure of technology management maturity (Wang *et al.*, 2007).

(2) Levels of TMMM. The ladder construction is also used in TMMM to position the level of technology management maturity, since the concept of maturity indicates that there might be a development process from one level of capability to a higher one (Jugdev and Thomas, 2002). Following the tradition of Capability Maturity Model (CMM), the ladder of technology management maturity also consists of five layers: initial level, defined level, managed level, benchmarking level, and continuous improvement level:

(1) *Initial level*. It is the basic level. In initial level, the enterprise may have a rough understanding of technology management, or have no consciousness of technology management at all. The procedures of technology management are random and undefined, and the execution of managerial activities is even disordered. In a word, technology management in this level still stays in the most primitive state.

(2) *Defined level*. In this level, the importance of technology management is recognized, and technical characteristics are comprehended. The basic courses of managing and controlling technologies are set up and can be repeated. Special departments responsible for technology management have been established.

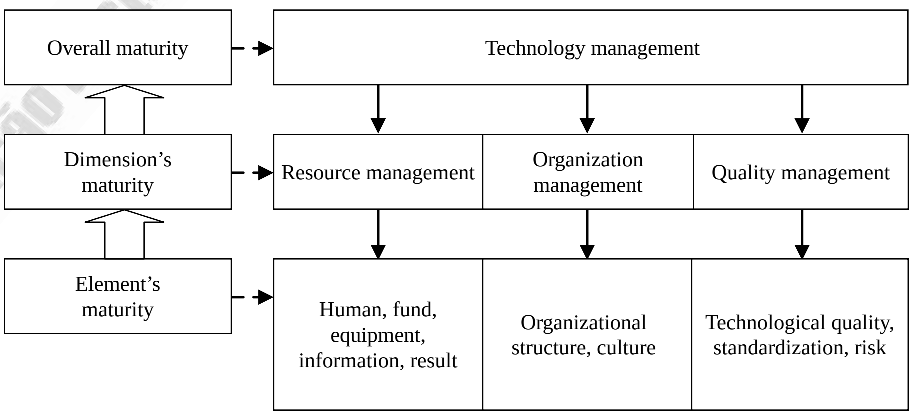

Figure 2.
The structure of technology management maturity

And technology management activities have been standardized and integrated with other management procedures.

(3) *Managed level*. In the third layer, appropriate measurements are set up, and special working team is established to control management processes and to evaluate management effectiveness. In this level, the enterprise establishes the technology management system in which technology activities are completely managed and controlled.

(4) *Benchmarking level*. Benchmarking is a very useful tool for improvement (Vorhies and Morgan, 2005). In this level, practices of technology management of the enterprise are compared with those of outstanding enterprises, and useful experiences are absorbed. The information from benchmarking can be used to improve technology management processes and methods and to promote technological competitiveness. Enterprises in this level have had the ability of preliminary continuous improvement and constant optimization.

(5) *Continuous improvement level*. Continuous improvement is to optimize implementation procedures according to the information fed back from former ones. In this level, the enterprise evaluates new technologies and technological changes through analyzing the current procedures, and finds out mistakes and corrects them. It also summarizes successful experiences and applies them to make continuous improvement possible and to reach excellence.

(3) The framework of TMMM. The five levels of technology management maturity conclude different states of technology management. TMMM integrates these levels with technology management elements and terms and takes on a matrix form (Table I) (Wang *et al.*, 2007). The statistical techniques are used to assess the maturity of each element, and elements' maturities are averaged to get the overall technology management maturity.

B. Fitness landscape and NK model of technology management

Fitness landscape theory offers a useful insight into how to measure fitness contribution of each variable in a complex system and provides discerning and testable

Technology management maturity Element	Term	Initial level	Defined level	Managed level	Benchmarking level	Continuous improvement level
Resource management	Fund management					
	Equipment management					
	Human resource management					
	Information management					
	Achievement management					
Organization management	Culture management					
	Structure management					
Quality management	Quality management					
	Standardization management					
	Risk management					

Table I.
The framework of TMMM

hypotheses of the relationship between fitness level and performance (Jermias and Ganti, 2004). The original theory was used in biological science to measure the degree of fitness among subsystems and how fitness affects the ability of an evolving system to survive and produce offspring. Fitness is defined as a proper match among the subsystems within the evolving system, which represents the ability of the evolving system to survive. Fitness landscape theory asserts that fitness contributes positively to the level of survival of an evolving system. Higher fitness values indicate a better chance of survival. Throughout its lifecycle, the system engages in a process of moving from one combination to another in search of an improved fitness until it reaches the global optimum (Frenken, 2006). Organizational and management scientists also make use of this model and argue that since organizational systems do not sexually reproduce, fitness reveals itself in terms of the ability of organizations to survive which are often measured by their performance (McCarthy and Tan, 2000).

In order to simulate the fitness landscape, Kauffman proposed the NK model which has attracted a wide attention in the field of biological science (Kauffman, 1995). The N represents number of variables or subsystems of the evolving system. Each variable may have a number of alternative forms or states denoted by A and makes a fitness contribution which depends on that variable and interconnectedness with other variables denoted by K. K ranges from 0 to $N-1$ where 0 indicates no inter-connection between variables and $N-1$ indicates the maximum possible interconnection among variables that may exist. In general, the number of combinations of a system with N variables, K interconnectedness and A alternative states is A^N.

Fitness landscape can be used to illustrate the processes of a system's evolution, so we employ fitness landscape theory and NK model to explore the relationships among technology management elements, and to design the roadmap of the development of technology management capability. Here we use a point to represent a possible combination of technology management elements, and use its height to represent the fitness of each possible combination, taking the grid to three dimensions. The grid is now a mountainous landscape of high-performance peaks and low-performance valleys (Levinthal, 1997).

A critical issue to apply fitness landscape theory to technology management is the definition of fitness and how we assign fitness value to each combination (McCarthy, 2003). Fitness of technology management can be regarded as a proper match among the elements, which represents the ability of the technology management system to survive in the market place or the ability to adapt to the change of environment. As we have known, the ability of survival and adaptation can be represented by organizational performance, and thus we assign the fitness score of one element combination according to the enterprise's performance.

Variables in NK model applied in technology management are endowed with concrete meanings concerned with technology management. N represents the number of elements of technology management, and $N = 3$. A denotes each element's state. In technology management, we consider the simplest case represented by a binary code where 1 is the good state and 0 is the bad state. Thus, $A = 2$. K denotes the interconnectedness of one element with other elements, and here $K = 2$ since they are interacted with each other. And the number of combinations of technology management elements is $2^N = 2^3 = 8$. Table II illustrates these combinations.

And the Boolean hypercube can be used to depict the fitness landscape of technology management (Figure 3).

It can be seen in Figure 3 that there exists the global optimum, and there are many routines to reach it. The routines are formed by adjusting one element in each step. However, there is only one routine in which the enterprise can gain the best fitness in each step which is displayed by arrow lines in Figure 3. We call this line the optimal routine, for although other routines can reach the global peak, the fitness will decrease in the course, which may bring about the risk of failing in the market. That is to say, to be optimal, technology management must engage in a process of moving from one combination to another in search of an improved fit. The fitness landscape of technology management just provides the suitable tool to find out the optimal combination, so we use it to set goals and design the routine in strategic planning for technology management.

IV. Research method

A. Questionnaire design

The questionnaire consists of two parts. Part 1 is designed for collecting the respondents' perceptive views on the high technology enterprise performance (EP). The performance is measured along three dimensions: managerial performance, market performance and R&D performance (Homburg and Pflesser, 2000; Coombs and

Combination	Resource management state	Organization management state	Quality management state	Fitness of technology management
000	Bad	Bad	Bad	0.125
001	Bad	Bad	Good	0.250
010	Bad	Good	Bad	0.375
011	Bad	Good	Good	0.625
100	Good	Bad	Bad	0.575
101	Good	Bad	Good	0.585
110	Good	Good	Bad	0.500
111	Good	Good	Good	0.825

Table II. Combinations of elements of technology management

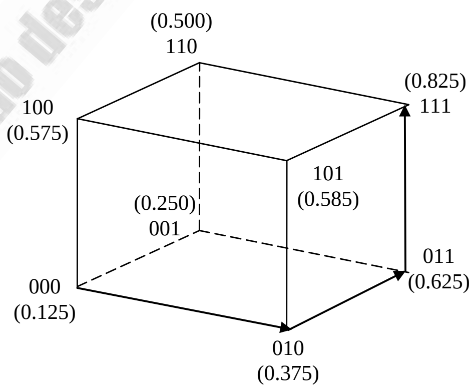

Figure 3. Technology management fitness landscape

Bierly, 2006; Dai and Liu, 2009). And 14 statements are developed for measuring, including productivity of the group, customer satisfaction, operating efficiency, R&D project success ratio, and new product development cycle.

Part 2 is designed based on the theoretical framework of TMMM to collect the views on technology management capability. It has 58 statements. Table II shows how the 58 statements of the questionnaire are distributed across the three elements and ten terms.

All statements are assumed to have the same weight. A scale of five choices, ranging from “disagree completely” (1) to “agree completely” (5), was adopted to measure the responses (Table III).

The maturity levels of three elements are defined as a one to five point Likert Scale, with a one being the lowest level and a five being the highest level. The average scores for each statement are calculated to determine the score of each term. Terms’ scores are then combined and analyzed to calculate a maturity level of each element and then are averaged to determine the overall technology management maturity.

The questionnaire has been pretested on two high technology enterprises in order to confirm its validity. The results of the pretest confirmed that the questionnaire was appropriate and the overall research methodology was valid.

B. Sample and data collection

We contact 43 enterprises in high-tech industry in China to collect technology management practice data. These enterprises operate in a variety of sectors including aerospace industry, information industry, biopharmaceutical industry, advanced material industry, and electronic device manufacturing industry, and are distributed across high and new technology development zones in Beijing, Hei Longjiang province, Liaoning Province, Shanxi Province, Gansu province and Jiangxi province. The average R&D intensity of these enterprises is 10.8, which indicates the important characteristic of the high technology enterprise.

The questionnaire we developed is used to collect data. Top or senior managers of these enterprises are invited to participate in the study since they master the holistic conditions of technology management in their enterprises and can provide abundant and effective information. They were asked to fill out the questionnaire and send it back preferably to the researchers by fax or other ways.

Elements	Terms	Numbers of statements	
Resource management	Fund management	6	32
	Equipment management	5	
	Human resource management	8	
	Information management	6	
	Result management	7	
Organization management	Culture management	4	10
	Structure management	6	
Quality management	Technological quality management	4	16
	Standardization management	7	
	Risk management	5	

Table III. The distribution of statements

V. Data analysis and results

A. Technology management state

The result of the survey of 43 high technology enterprises shows that the highest score of enterprise maturity is 4.58 and the lowest score is 2.89. And the average technology management maturity for all enterprises is 3.86, which may indicate the holistic level of technology management capability of China's high technology enterprises. According to the meanings of the maturity level, the score of 3.86 implies that in general China's high technology enterprises have reached the managed level. That is, most of high technology enterprises set quantitative quality goals for both technology products and processes. Productivity and quality are measured for important technology process activities across all projects as part of an organizational measurement program. Technology management processes are instrumented with well-defined and consistent measurements. The enterprises have the means to identify weaknesses and strengthen the process proactively, with the goal of preventing the occurrence of defects. But this state is far from satisfying in the condition of severe competition that China's high technology enterprises are facing in the world market. There lacks the references made from experiences of excellent enterprises and the organization-wide technology management database used to collect and analyze the data available, and the quantitative foundation for evaluation is not established. Thus, innovations that exploit the best practices cannot be identified and transferred throughout the enterprise, and furthermore the entire organization cannot be focused on continuous process improvement.

Maturities of elements are also in our interests. To calculate the average maturity of each element, all enterprise's maturities of the selected element are averaged. The result shows that maturities of three elements range from a low of 3.64 for quality management to a high of 4.10 for organization management (Table IV). Since the rating scale ranged from one to five, this means that there still leaves much room for improvement of technology management practices in China's high technology enterprises. Among them, organization management has the highest maturity, while quality management has the lowest maturity and needs to be paid more attention in improvement.

High technology enterprises are knowledge or technology intensive in which most of employees are brainpowers with good educational qualifications (Neelankavil and Alaganar, 2003). The employees have not only good intelligence but also innovation spirit and pioneering spirit, and they are good at accepting new management principle and thinking. Thus, an innovative culture can be easily established and accepted in high technology enterprises. And China's high technology enterprises lay great emphasis on the organizational structure management in response to the call of reformation of enterprises by the government with the result that the modern enterprise system has been accepted in most high technology enterprises, and special R&D departments are

Descriptive statistics	Resource management	Organization management	Quality management	MoT
Mean	3.83	4.10	3.64	3.86
SD	0.11	0.10	0.08	
Median	3.87	4.13	3.72	

Table IV. Elements' and the overall maturities of all 43 enterprises widely established (Mu, 2007). Emphasizing on organizational issues results in the maturity reaching the higher level than that of resource management and quality management.

Although the quality of product and process is laid great emphasis on by China's high technology enterprises, the deficient management of risk and standardization makes the score of quality management maturity the lowest. In firm level, risk management is expected to provide an essential foundation for sustaining competitive advantage (O'Donnell, 2005). But in China, effective risk assessment system is not established in most enterprises, and measures for avoiding and transforming technology risk, market risk and financial risk are not designed and implemented. And in the field of standardization management, many enterprises, newly founded enterprises especially, pay less attention to managerial standardization than to technological standardization, and the scientific study of standardization is ignored. These are all issues that should be improved.

B. Fitness landscape of technology management

(1) Data processing. In order to depict the fitness landscape of technology management, we should further process the data of maturities of technology management elements and enterprises' performance. First, scores of elements maturities and EP are transformed into values between 0 and one using the following formula:

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}}$$

where x is the score of technology resource management maturity (TRM), technology organization management maturity (TOM), technology quality management maturity (TQM), or the EP, $x_{\min}$ is the minimum value and $x_{\max}$ is the maximum value. The transformed variables are represented by ZTRM, ZTOM, ZTQM, and ZEP.

Second, we distinguish the states of TRM, TOM and TQM by comparing the values of ZTRM, ZTOM and ZTQM with 0.5, and we mark the state in which the value is more than 0.5 as one and the state in which the value is less than 0.5 as 0. Thus, one represents that the capability of one element is above the average and is in good state, and 0 represents the bad state. And then the eight combinations of technology management can be distinguished.

Third, we calculate the arithmetic mean of ZTRM, ZTOM, ZTQM, and ZEP values of all enterprises in one combination and mark them as AZTRM, AZTOM, AZTQM, and AZEP. AZEP is the average performance that enterprises in one combination have achieved and it represents the fitness of the combination.

(2) Fitness landscape depiction. Table V shows the combinations of technology management of China's high technology enterprises, and the values of AZTRM, AZTOM, AZTQM, and AZEP.

From the above table, we find that the 000 combination has the lowest fitness (0.057), and the 111 combination has the highest fitness (0.816). Further observation indicates that combinations of 011, 101, and 110 have the higher fitness than combinations of 001, 010, and 100. Since 0 and one represent the different states of low and high maturities, and the more the one appears in one combination, the higher its maturity is, it can be proved that the higher the level of technology management capability is, the better performance high technology enterprises can achieve.

According to Table V, the fitness landscape of technology management of China's high technology enterprises can be depicted as Figure 4.

In this landscape, 111 is the global "peak" and 000 is the "valley." The landscape is rugged because there are other peaks and valleys. Although we say that elements in 000 and 111 are more "coordinated" than other combinations for they have similar state, obviously, only in the global peak can the technology management system gain the best adaptation to the environment for the fitness value of this combination is the highest. Thus, we regard reaching the global peak as the ultimate goal of developing technology management capability.

C. The routine for the development of technology management

Formulating the strategic planning for technology management is an evolutionary search for the highest point in the fitness landscape. It can be seen in Figure 4 that there exist many routines from the valley to the global peak: 000-100-110-111, 000-100-101-111, 000-010-110-111, 000-010-011-000, 000-001-101-111, and 000-001-011-111. But only in the routine of 000-100-110-111, can the highest fitness be gained in each step, and thus we argue that this routine is the optimal routine which is denoted by lines with arrowhead in Figure 4. This optimal routine shows the change of elements' states in promoting technology management capability. And it clarifies the order of promoting elements' capabilities. According to this routine, in order to achieve the best adaptation or the best performance in each step of promoting technology management capability of China's high

State	AZTRM	AZTOM	AZTQM	AZEP
111	0.728	0.793	0.765	0.816
110	0.643	0.850	0.495	0.518
101	0.613	0.490	0.572	0.513
100	0.583	0.100	0.309	0.486
011	0.278	0.650	0.704	0.660
010	0.241	0.500	0.243	0.348
001	0.390	0.457	0.500	0.476
000	0.162	0.117	0.206	0.057

Table V. Technology management parameters of high technology enterprises in China

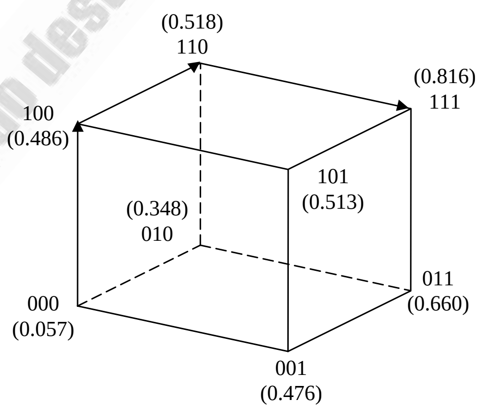

Figure 4. Technology management fitness landscape of high technology enterprises in China

technology enterprises, the resource management capability should be promoted first and then the organization management capability, and based on which the quality management capability can be promoted.

This optimal routine is in essence the result of the accumulative and dependant relationships among resource management, organization management and quality management. Effective resource allocation and control is the basis of all activities in an enterprise, and the capability of resource management should be the first to be promoted in the development of technology management. As far as high technology enterprises are concerned, R&D and technological innovation play very important roles in building the enterprise's competitiveness (Chen and Yuan, 2007; Yun, 2009). Managing innovation is the main issue in technology management and the fitness to some extend can be regarded as the result of innovation quality management. According to Haner (2002), innovation quality has three levels: a product/service level, a process level and an enterprise level. In each level, two aspects should be taken into consideration: the redistribution of factors of production, and division of labor and coordination of work. Organization management exerts crucial influence on the two aspects, in that effective organizational structure can provide the prerequisite to resource redistributing and work coordinating, and innovative culture can create suitable environment for R&D and technological innovation by popularizing the common values and philosophy of the enterprise (Scott, 2000; Lei and Slocum, 2005). Therefore, organizational structure and culture serve as the basis of innovation quality management, and organization management should be promoted before quality management in order to provide it with a sound basis.

The optimal routine demonstrates the direction for adaptive evolution of technology management system of China's high technology enterprises and also sets the goal of each step. Now we argue that three steps should be taken in promoting technology management capability. The first step is chiefly to promote capabilities of human resource management, fund management, equipment management, information management, and technological result management to reach the "good state." The second step's goal is to establish suitable and effective organizational structure and organizational culture with a development and innovation orientation. And the third step, based on the antecedent two steps, is chiefly to strengthen quality management capability and to gain the excellence of innovation quality. However, this does not mean that only one element should be developed in each step. On the contrary, all elements should be taken into consideration at the same time according to the principles of strategic planning for technology management, and the routine only reveals the differences of development emphasis in each step.

VI. Discussion and implications

This paper contends that strategic planning for management of technology is necessary and important for China's high technology enterprises. The objective of this paper is to explore, describe, and explicate the processes related to strategic planning for technology management, and to provide beneficial suggestions for China's high technology enterprises to promote technology management capability. Therefore, the model for strategic planning for technology management is developed. CMM and fitness landscape theory are applied in this model to construct useful analysis tools. The model is used to make the strategic planning for technology management of

China's high technology enterprises. A survey of 43 high technology enterprises in China is conducted, and according to the data, TMMM is used to assess the technology management level and fitness landscape of technology management is developed to explore the routines of promoting technology management capability. We find that there is still much room for China's high technology enterprises to improve technology management capability since the average technology management maturity is only in the managed level. And the maturity of quality management is lower than that of organization management and resource management, and so quality management should be attached more importance to in promoting holistic technology management capability. All such findings imply that our research makes theoretical contributions to technology management and strategy related literature with significant managerial implications.

A. Theoretical implications

For the past several years, technology management has been dominated by views advocating capability building. Yet to date, little is known how technology management capability is promoted. Our research provides an operational methodology for such a test. Specifically, we contribute to technology management related literature in more ways than one.

First, we contribute to technology management literature by constructing the model of strategic planning for technology management, viewing it as the roadmap of the development of technology management, explaining three interrelated points (element/behavior, co-ordination, and adaptation), and illustrating three processes (identifying current conditions, setting development goals, and designing the development routine), all of which have been emphasized by previous studies.

Second, we use fitness landscape and NK model to explore the routines of promoting technology management capability. The fitness landscape and NK model for technology management are developed, where we argue that different combinations of elements of technology management have different "fitness" which is represented by organizational performance. This provides us with a very useful and convenient tool to design the roadmap of the development of technology management.

B. Managerial implications

This research also offers issues that could add to our understanding of technology management practices in China's high technology enterprises, and thus provides several guidelines for improvement of technology management capability.

The findings of the study highlight the importance of technology management in high technology enterprises. The study has empirically examined the relationship between technology management capability and EP in China's high technology enterprises. The findings indicate that the enterprise with higher technology management capability level can achieve better performance. Since technology management can be decomposed into three categories of elements (resource, organization, and quality), the managerial implication is that all elements should be emphasized and technology management should be improved in all its aspects.

Our findings also shed light on the roadmap of promoting technology management capability of China's high technology enterprises. Although we emphasize the harmonious development of technology management elements, this does not mean that the element with the lowest maturity should be improved firstly or the three elements should be improved simultaneously without difference. During the course of improvement, a certain order should be followed due to the rule existing in the interactions of technology management elements. This study explores the relationships among the three elements and the results show that the order by which the element should be laid emphasis on is "resource management – organization management – quality management." This reveals the routine of the development of China's high technology enterprises. The managerial implication is that to high technology enterprises in China, high quality is based on effective organization and resource management, and excellent organizational issues rely on effective resource management. This explains the dependency relationships among managerial variables in technology management which determine the difference between high technology enterprises and others.

C. Limitations and further research

This study does of course have its limitations. First of all, although the enterprises analyzed in this study are technology-intensive and cover some subindustries, these enterprises are mostly state-owned enterprises and may not represent the whole of the high technology industry totally. Thus, interpretation of the findings from our study should be conservative. Second, since the findings of this study are based on data from a survey, personal bias due to subjective responses to the questionnaires should be taken into considerations. Thirdly, the landscape is not fixed. As the environment changes, the fitness landscape will also change, which may affect routine selection. We leave this for future research.

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