Chapter 2
A Conceptual Framework of Tech Mining Engineering to Enhance the Planning of Future Innovation Pathway (FIP)

Munan Li

Abstract Given the importance of innovation pathway and to meet the rapid growth of tech mining requirements, a novel conceptual framework for tech mining engineering (TME) is proposed to enhance the planning of future innovation pathway. Especially for those small and medium-sized enterprises (SMEs). The framework is intended to improve or guarantee the quality and efficiency of tech mining using engineering methodologies and technical standards. Certain basic elements of TME are defined and illustrated and the enormous potential and promising market for TME are discussed as subjects of future research and applications.

Keywords Tech mining · Innovation strategy · TME (Tech mining engineering) · Strategy-oriented methodology · Future innovation pathway · Top-down model of process

2.1 Introduction

With the convergence trend of science and technology (S&T), and rapid emergence of the new technologies and materials, future innovation pathway (FIP) has become a critical issue for the enterprises (Harold 2011). Obviously, FIP-oriented decision-making and planning is a definitely complicated engineering. Based on the basic philosophy of tech mining, Guo et al. (2012) ever proposed a systematization of the 'Forecasting Innovation Pathways' analytical approach to facilitate the relevant decisions.

"Tech mining" is defined as the text mining of technological information resources, and its functionality depends on a deep understanding of innovation processes (Porter and Cunningham 2005; Porter 2007). In the traditional, naïve framework of tech mining, the key elements include a TIPM (Technology

M. Li (✉)
School of Business Administration, South China University of Technology, Guangzhou, People's Republic of China
e-mail: limn@scut.edu.cn

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Innovation Process Model), FOT (Future-Oriented Technology), R&D data selection, IR (Information Representation), Data Treatment, Innovation Indicators, and so on (Porter 2007). Although tech mining appears to be the application of text mining in technology management and innovation management, it is significantly different from data mining and text mining in both its perspective and methodology. Data mining, text mining and KDD (Knowledge Discovery in Database) focus on analytical models and algorithms for structural, semi-structural and non-structural data based on mathematical modeling. Therefore, text and data mining provide a framework of methods and tools, and their key elements or concerns are the efficiency, accuracy, robustness and flexibility of algorithms and mathematical models. Generally, data and text mining is method-oriented or tool-oriented engineering; however, tech mining is often utilized to support strategic decision-making in technology innovation and R&D management and can therefore be considered to be strategy-oriented engineering. TME (Tech Mining Engineering) itself is a very new concept in the literature, and only a few large-scale organizations, e.g., the strategic departments of governments, MNEs (Multi-National Enterprises) and research institutes, have utilized TME techniques and tools to support management activities related to innovation strategy for any length of time.

Considering the promising value of tech mining for FIP, it should not remain the privilege of MNEs; SMEs (Small and Medium Sized Enterprise) should also be able to harness this capability to enhance their innovation management, planning of FIP and approach competitive advantage by learning or outsourcing the service. Hence, an engineering framework for tech mining appears to be a meaningful and necessary method by which SMEs and even larger scale organizations can gain important guidance on aspects such as team management, work flow or process optimization, evaluation rules for quality and control policies for cost and quality under a uniform engineering framework or model.

2.2 Literature Review

According to the strategic pathway and innovation capabilities, Branzei and Vertinsky (2006) argued that the significant connections between innovation pathway and capabilities. Therefore, the planning of FIP should be considered in the level of organizational strategy. However, for those SMEs, the related issues to FIP could not be the easy tasks at all, and tech mining could become an important tool for SMEs to facilitate the planning of FIP (Porter and Newman 2011; Huang et al. 2012; Guo et al. 2012; Mittra et al. 2015).

Using the key word “tech mining” to search for articles published in journals collected in the core database of Web of Science (WoS™) returns almost 75 articles, some of which are noise. Using the key word “text mining” for the same period (2004–2014), however, yields over 3000 records. Considering the critical relationship between “tech mining” and “text mining” several search experiments were performed with different combinations of topics (key words) in such categories as *Management, Operation research management science, Business, Planning development, Industrial engineering, Engineering manufacturing, Economics,* Multidisciplinary engineering, and *Information science and Library science*; the experimental results are shown in Table 2.1.

Table 2.1 Relevant literature in WoS™ under different combinations of topics (2004–2014)

Topic (key words)	Search results	Representative authors (Count of publications)	Representative Journals (Count of records)
Tech mining	75	Porter A.L. (13), Miyazaki K. (5), Cunningham S.W. (5), Newman N. C. (5)	Technological forecasting and social change (9) Technology analysis strategic management (6) Expert systems with applications (4) Technovation (4)
Tech mining engineering	**0**	**None**	**None**
Tech mining and text mining	14	Porter A.L. (7), Guo Y. (3), Kostoff R.N. (2), Newman N.C. (2)	Technological forecasting and social change (3) Technology analysis strategic management (2) Advanced materials research (2)
Text mining and patent analysis	80	Anderson T.R. (6), Daim T.U. (6), Kocaoglu D.F. (6)	Expert systems with applications (15) Scientometrics (9) Technological forecasting and social change (8)
Text mining and bibliometrics analysis	40	Kostoff R.N. (12), Porter A.L. (5), Bhattacharya S. (4), Glanzel W. (4)	Technological forecasting and social change (8) Scientometrics (5) Current Science (2)
Text mining and technology Roadmapping	14	Yoon B. (4), Gomila J.M.V. (3), Phaal R. (3), Porter A.L. (3), Zhang Y. (3)	R&D Management (3) Scientometrics (2) Technological forecasting and social change (2) Technology analysis strategic management (2)
Text mining and technology opportunity analysis	25	Yoon B. (8), Porter A.L. (4) Yoon J. (3)	Expert systems with applications (4) Scientometrics (3) Technological forecasting and social change (3) Industrial management data systems (2)
Text mining and competitive intelligence	24	Porter A.L. (4), Gomila J.M.V. (3), Zhang Y. (3), Zhou X. (3)	Scientometrics (3) Decision support systems (2) Data mining VII data text and web mining and their business applications (2) Industrial management data systems (2)

Beyond the information contained in Table 2.1, we note the interesting phenomenon that citations rarely cross between "text mining" and "tech mining." A count of the records in Table 2.1 shows the number of relevant studies to be fewer than 300, with apparently zero studies on tech mining engineering (TME).

Here, when using the narrow definition of tech mining—the "text mining of technical information resources" (Porter and Cunningham 2005; Porter 2007)—tech mining is an application based on text mining technology that is used in technology and innovation management. Therefore, in most related studies, tech mining is often taken as a tool, process or integrated framework that supports R&D management and innovation strategy planning. For example, Trumbach et al. (2006) described a method of tech mining used to keep small businesses knowledgeable about innovation ideas. Combing tech mining with bibliometrics analysis, Miyazaki and Islam (2007) explored differences between the U.S., Japan and the European Union in terms of the innovation pattern of nanotechnology. Nazrul and Kumiko (2010) analyzed the strengths and weaknesses of different countries in nanotechnology research based on tech mining techniques.

Porter and Newman (2011) proposed a five-stage framework of tech mining to answer typical questions in technology management. Park et al. (2013a, b) adopted TRIZ evolution trends as criteria for evaluating technologies in patents. Zhang et al. (2014) provided six "term clumping" steps that clean and consolidate topical content in such text sources. Becker and Sanders (2006) illustrated how tech mining could profit from innovations in meta-analysis and social impact assessment. Newman et al. (2013) compared alternative ways of consolidating messy sets of key terms. Some researchers have argued that tech mining may present an alternative or potentially complementary way to determine support for emerging technologies using proxy measures such as patents and scientific publications (Hopkins and Siepel 2013). Jose and Fernando (2013) provided a solution for tech mining by combing the semantic–TRIZ for a better technology analysis technique. Based on the patents, other researchers advanced a Subject-Action-Object (SAO) technique for text mining and utilized it to improve the process of technology road mapping (Yoon and Kim 2011; Choi et al. 2013).

Supporting decision-making in innovation pathway, future-oriented technology forecasting is one of the most important tasks in tech mining (Porter 2007). Based on traditional text mining, Ghazinoory et al. (2013) provided a method for locating technology centers of excellence. Aiming at the issue of selecting technology forecasting methods, a multi-criteria fuzzy group decision-making approach was proposed to improve accuracy (Gizem et al. 2013). Guo et al. (2012) discussed the issues surrounding technology forecasting and innovation pathway selection based on text mining information resources.

Actually, tech mining can be understood as an integrated framework or process that can combine many traditional and emerging analytical techniques to enhance planning or decision-making of FIP including technology forecasting and technological opportunity analysis (Newman et al. 2013; Halme and Korpela 2014; Li 2015). Porter ever used the term "supply chain" to describe the process that brings high-quality intelligence to support R&D management (Porter 2007).

Theoretical research on the framework and process of tech mining is still scarce, however; most studies prefer to use tech mining as a tool or method to improve empirical research, e.g., to enhance patent analysis using text mining techniques (Tseng et al. 2007), to identify promising patents or to forecast emerging technology evolutions by combining tech mining with TRIZ (Park et al. 2013a, b; Li 2015), or to identify promising opportunities for products or markets by combining text mining with quality function deployment (Jin et al. 2015).

In summary, aiming to FIP, the basic framework of tech mining brings an integrated solution covering many aspects in technology management and strategic analysis. However, the engineering architecture for the real implementation of tech mining seems insufficient for those different types of organizations, particularly for the SMEs.

2.3 Research Questions and Methodology

2.3.1 Why Does Engineering Need Tech Mining?

With the rapid development of emerging technology and the growth of information resources, finding a way to refine innovation strategy, planning of FIP and improve the capability of innovation management has become a significant challenge for all types of organizations. Under the scrutiny of tech mining, there are several incentives for designing an engineering framework for tech mining applications.

First, S&T development is a double-edged sword that can bring both positive effects and negative influences. Halme and Korpela (2014) argued that a responsible innovation pathway should naturally connect to sustainable development. Future-oriented technology forecasting is an important issue in tech miming, although no organization can guarantee that the output of tech mining will be accurate if engineering methodologies and standards are not applied. Clearly, engineering tech mining may moderately reduce the risk inherent in technology innovation.

Second, although each organization develops its innovation pathway independently, the progress of economic globalization ensures that the innovation strategies of nations, territories, industries and enterprises cannot be separated from the world. Competition and cooperation coexist in the issues of development; therefore, the concrete programs of tech mining must confront an environment growing in complexity and competitive issues at both macro and micro levels. In addition to traditional analytical techniques, e.g., patent analysis, technology foresight and forecasting, competitive intelligence collection and so on, the tools of strategy management, such as PEST (Political, Economic, Social and Technological Analytical Model) and SWOT (Strength, Weakness, Opportunity, Threats Analytical Model), should be integrated into the tech mining process. Further, some data mining and text mining techniques, in addition to engineering management tools, are necessary to the actual delivery of tech mining.

Third, innovation pathway planning is not an independent activity; strategic decision-makers should be aware of the harmony and matching issue between innovation strategy and the innovation ecosystem (Adner 2006). Considering the context-dependent preferences in strategic decision-making for disruptive innovations, followers and pioneers can choose different pathways for technological improvement in a dynamic situation (Chen and Turut 2013). Bowonder et al. (2010) made 12 strategic suggestions for a company to obtain a competitive advantage. Even with tech mining, determining an organizational innovation strategy remains a complicated mission, and this process requires an engineering framework to reduce the risk.

In addition, with the rapid growth of text mining technology, an increasing number of analytical methods and techniques can be integrated into the tech mining framework (Tseng et al. 2007; Wang et al. 2012; Wong et al. 2014; Wood and Williams 2014; Yoon et al. 2014). Hence, a real tech mining project should take into account complicated systems engineering, which involves many different technologies and professional experts, e.g., innovation management, information and library science, computer science, mathematical modeling, and so on. In managing a team and coordinating cooperation among experts, engineers need the standard engineering framework to guarantee the schedule and the quality of related activities.

Finally, an engineering framework for tech mining can bridge the theoretical research and the potential market for tech mining services. Although most nations and MNEs (Multi National Enterprises) may have established their tech mining teams, SMEs still lack the related services or products due to costs and their more limited capabilities. Thus, the standardization of tech mining engineering may foster a promising market for tech mining services in the future.

2.3.2 Research Questions

The role of engineering in tech mining and the architecture of tech mining engineering (TME) appear to be prominent research gaps based on the above literature review. According to the basic components and activities defined in tech mining (Porter and Cunningham 2005), it can be inferred that strategic decision-makers should be the end-users of tech mining. The previous literature does not detail, however, whether the process of tech mining should be adjusted to meet the different scales of organization (nation/territory, industry and enterprise). After all, innovation strategy or technology development pathways could be very different at the different levels (macro, industrial and micro). Because of this variation in level, i.e., the macro (national), industrial and micro (enterprise) levels, strategy-oriented tech mining engineering could encounter challenges in adaptability and flexibility. Meanwhile, the purpose and main task of TME is to enhance organizations' innovation management capabilities and competitive advantage. The main content and topics of naïve tech mining are dynamic, and many new analytical methods and tools may be integrated into the framework, including social network analysis, cloud computing, big data, and so on.

Based on the analysis of related literature, most researchers see tech mining as a method for exploiting new technology to enhance traditional patent analysis, technology opportunity analysis, CIC (Competitive Intelligence Collecting), TRM (Technology Road Mapping) and so on (Phasl et al. 2004; Salles 2006; Shi et al. 2010). For strategic decision makers, however, several questions must be answered:

- When is tech mining necessary?
- What are the targets and final outputs of tech mining for different types of organizations?
- What types of experts should be pulled into tech mining projects?
- Who are the end-users or real customers of tech mining?
- Who can provide tech mining sourcing services?
- Where is the market for tech mining?
- How do you begin a tech mining project for organizational FIP?
- How do you schedule tech mining activities?
- How do you accurately evaluate and control costs with the right polices and regulations?
- How do you objectively assess the quality of different phases of tech mining in addition to the final product?

Based on the above questions regarding the practices of tech mining, an engineering framework is necessary. The research questions are as follows:

Question 1: What is tech mining engineering? (Definition, goals, implementing team, roles, responsibilities, inputs/outputs, and so on)
Question 2: What is the process model of TME, or how do you regulate and guide the tech mining activities?
Question 3: What is the mechanism of quality assurance?

2.3.3 Methodology

According to the basic definition of tech mining, the critical outputs appear to be intelligence, future-oriented forecasting and technology road mapping so forth, which can be integrated into enhancing the planning of FIP, all of which are important to organizations' strategic decision making, especially the innovation strategies of a technology or industry. Recently, some researchers have begun to integrate tech mining into innovation and strategy management; further, the international journal "*Technology analysis and strategic management*" published a special issue on "tech mining and innovation management" in 2013, indicating that it is an attractive and promising methodology for building interactions with innovation strategy planning and management. In turn, organizations' strategic behavior and intentions could influence the targets and processes of tech mining in unseen and profound ways. For example, different perspectives, competitive strategies and marketing campaigns could engender entirely different requirements for tech mining engineering. Facing the rapid development of emerging technology, the choice between exploration and exploitation renders the need to consider many variables quite complicated (Fauchart and Keilbach 2009).

As a key technique in tech mining, technology road mapping is not only an opportunity for technology analysis but also requires the integrated analysis of opportunities in the market (Groenveld 1997; Kostoff and Schaller 2001; Phasl et al. 2004; Lee et al. 2009). Further, technology road mapping provides important decision support for innovation strategies and FIP. In addition, as another important support tool of innovation strategy, technology foresight is facing a similar challenge, i.e., how can we accurately evaluate and improve the quality of the technology foresight process under a certain technical standard (Linstone 2010; Miles 2010; Oliveira and Rozenfeld 2010). The research on the relationship between tech mining, strategic management and innovation performance improvement, however, seems to be just beginning.

When examining the basic definition, processes and framework of tech mining, it becomes clear that the innovation pathway planning or supporting documents for innovation management must be one of critical outputs. Therefore, a strategy-orientation, particularly innovation strategy, is the main methodology of TME framework design. The strategy-oriented methodology for tech mining engineering contains several aspects:

- TME is a complex engineering system that provides an integrated solution for different organizations to improve strategy planning and management.
- The core outputs of TME are organizations' innovation strategies.
- The main goal of TME is to enhance the planning of FIP and improve innovation capability and performance.
- The quality control mechanism in TME comprises the measurements, metrics, and rules in the phases of strategy planning, strategy implementation and strategy adjustment.
- The framework of TME is designed based on the basic engineering methodology in which processes, steps, techniques and tools are integrated to carry out the task of strategy planning and management.

Although we have defined the content and processes of tech mining, we have yet to explore how to embed these processes into the strategic decision-making of organizations. In fact, it is somewhat unclear whether and how tech mining processes will require adjustment to function within different organizations' strategic planning and who would lead the adjustment processes to meet different requirements.

A basic preparatory step before implementing a tech mining project is role configuration, the definition of which is an important element in defining cooperation and efficiency. The following questions concern quality control policies, which contain the definitions of measurements and metrics in addition to engineering evaluation and assurance techniques.

2.4 Tech Mining Engineering: Definitions, Targets, Organizations and Roles

2.4.1 The Definition of Tech Mining Engineering

Based on the background analysis and challenges surrounding tech mining described above, tech mining needs an engineering framework or architecture model to support the related management activities. It is clear that tech mining can enhance the FIP planning and operational management of different organizations, especially innovation or technology development strategies. Therefore, according to similar philosophies from other types of engineering, e.g., industrial engineering, software engineering and data mining engineering, tech mining engineering should define and improve the efficiency of tech mining, measure and evaluate the quality of activities related to tech mining, develop a mechanism for quality assurance via qualitative methods and tools, provide technical standards and references to improve the delivery of tech mining, promote the performance of innovation strategies, enhance organizations' sustainable capabilities, and retain the competitive advantages of an organization.

TME (Tech Mining Engineering) is thus defined as an interdisciplinary faculty that integrates multidisciplinary theories, methods, techniques and tools into its architecture, pulling from fields that include library and information science, computer science, management science, and so on. The mission of TME concerns factors such as the environment and resource analysis of innovation strategy, planning of FIP, R&D management, technology management, product innovation and coordination, team management and technical standards regulating and guiding practice, among others. The basic definition of TME leads us to divide it into three connected components:

- Models, algorithms and tools of tech mining based on library and information science, computer science and mathematics;
- Processes, work flows, regulations, rules and technical standards of tech mining based on engineering science and methodologies;
- Scheduling, team motivation, quality assurance mechanisms, cost control and performance evaluations based on management science.

These three components are united into the skeleton of TME, and the main target or perspective of TME is to enhance the strategic management of different organizations and then improve the capability and performance of innovation.

2.4.2 The Implementation of TME

According to the basic definition of TME, when implementing a tech mining project, the organizational targets, roles and responsibilities must be illustrated in the engineering framework. The consumers of TME could be nations (territories), industries or enterprises, and the providers could be government departments, universities, other research institutes, third-party companies, and so on. The outputs of TME can be divided into three types of innovation or technology development strategies based on the customer: macro (national), industrial or micro (enterprise).

In terms of the basic concept of tech mining, Porter (2007) did not recognize the potential differences among nations, industries and enterprises when planning an innovation strategy. For example, compared with an enterprise strategy, national strategies are oriented towards long-term development goals, the improvement of public governance, and enhancing national competitive advantage in the process of globalization. In contrast, at the industry level of innovation strategy, the core targets would be key technology innovation and the sustainable development and evolution pathway of industry. At the enterprise level, large enterprises and MNEs in particular differ from SMEs.

Industrial leaders should be willing to, and indeed must, undertake basic research and technology innovation to retain their leadership position. SMEs, however, must focus first on market survival and then on enterprise development. Therefore, the attitude towards investment in basic R&D and the targets of innovation strategy could be very different between MNEs and SMEs. In addition, the internal resources of tech mining could be very different. Many famous high-technology companies, e.g., *IBM, Microsoft, Huawei, SAP* and *Samsung*, have established professional tech mining teams. Most SMEs, in contrast, must seek external resources to meet their tech mining requirements. An illustration of TME consumers, targets, roles and providers is shown in Table 2.2.

Based on the information in Table 2.2, although TME also provides an intellectual product and service compared with software engineering, the output of TME is more difficult to measure and evaluate. Because TME outputs related to innovation-pathway planning or technology development are less tangible than the fruits of software or industrial engineering, they require a much longer evaluation period, if they can be evaluated at all. In contrast, the output of software engineering is much easier to test and evaluate. Therefore, objective evaluation and verification of TME may be a critical challenge.

In addition, compared with traditional software or industrial engineering, there are three levels of TME end-users: national (macro), industrial and enterprise (Micro). The final target could be the acquisition of competitive advantage for any of those levels, but the detailed prospectus, purpose and final outputs of tech mining at each level would remain significantly different. Meanwhile, the macro, industrial and micro strategies of innovation are also interrelated. For example, a particular national strategy for technology innovation would directly or indirectly influence an industry's development policies. The changes in development strategies and the

Table 2.2 Basic descriptions of consumers, targets and roles in TME

Consumers of TME	Level of innovation strategy	Targets	Roles (end-user, provider)
Nation (territory)	Macro level	• Planning national innovation strategies • Acquisition of national competition advantage	User: government decision-makers Provider: Research institutions (e.g., universities, S&T development research institutes, etc.), third-party consultants
Industry	Industrial level	• Planning industry innovation pathway and strategies • Sustainable development of industry • R&D in key common technologies • Harmonious governance between industry and environment • Development of industry ecosystem	User: industry policy-makers Provider: research institutes or professional third-party consultants (or leading industry enterprises)
Enterprise	Micro level	• Planning, implementing and monitoring technology evolution pathways • Improvement of innovation capability and performance • Acquisition of competitive advantage in the market	User: enterprise decision-makers, R&D managers Provider: enterprises' internal organizations, third-party consultants, research institutes

related policies of nations and industries could affect enterprises, especially SMEs, in a profound and significant way. In turn, the innovation strategies and activities of enterprises may indirectly influence the macro and industrial policies. The interactions among the three types of innovation strategies are presented in Fig. 2.1.

In Fig. 2.1, indirect interaction between macro and micro innovation strategies is presented, which may be the cause of debate. National innovation strategies clearly

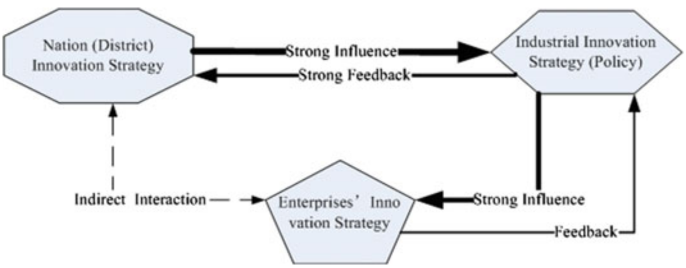

Fig. 2.1 The relationships among macro, industrial and micro innovation strategies

influence enterprise behaviors through industrial and financial policies. In turn, the significant innovation activities of enterprises provide important feedback for macro and industrial strategy management. In fact, an analysis of the content of various national innovation strategies shows that many words and topics overlap across different nations' innovation strategies. This phenomenon is illustrated in Table 2.3.

In addition to the sampling of national innovation strategies shown in Table 2.3, a majority of countries around the world have established innovation strategies, from which it can be inferred that competitive advantages and sustainable development are among the most prevailing global concerns. Based on national-level innovation strategies, industry and S&T development strategies and policies should

Table 2.3 Recent national innovation strategies

Innovation strategy	Nation	Open date	Linked webpage	Prospective
Chinese Manufacturing 2025	China	2015.5	http://www.ce.cn/xwzx/gnsz/gdxw/201505/19/t20150519_5402874.shtml	To promote the manufacturing industry via innovation
Innovation Driven Development Strategy	China	2015.3	http://www.sipo.gov.cn/dtxx/gn/2015/201506/t20150608_1128472.html	To enhance economic development via innovation driven force
Strategy for American Innovation	U.S.	2010.11	https://www.whitehouse.gov/innovation/strategy/introduction	To motivate innovation for sustainable growth and quality jobs
Innovation Nation (White paper)	U.K.	2008.3	https://www.gov.uk/government/publications/innovation-nation	To build an innovation nation in which innovation thrives at all levels
Japan's Innovation Strategy toward Asia	Japan	2014.3	http://www.mof.go.jp/english/pri/publication/pp_review/ppr024/ppr024d.pdf	To enhance innovation cooperation and keep competitive advantages
The 6th Plan of industrial innovation (2014–2018)	Korea	2013.12	http://1048.edu.pinggu.com/forum/201406/04/41f9e4b5b414/(3)6_(2014-2018)().pdf	To drive the development of key technology innovation in several critical industries in Korea
Three-year plan for economic innovation	Korea	2014.2	http://www.korea.net/NewsFocus/Policies/view?articleId=117839	To motivate sustainable and innovative economic development
Poles of Competitiveness	France	2004.9	http://competitivite.gouv.fr/home-903.html	To develop a competitiveness cluster in France
High-Tech Strategy 2020 for Germany	Germany	2010.7	http://www.bmbf.de/en/publications/index.php	To promote several high-tech German industries via innovation

be adjusted to meet the requirements of the relevant macro strategies; furthermore, enterprise and research institutes should consider aligning their strategies with their respective national priorities.

Two interesting and puzzling questions remain: (1) how were these national innovation strategies composed? And (2) how can we evaluate these macro strategies, particularly in terms of their suitability? For example, the latest US innovation strategy, "Reviving the Manufacturing Sectors of the United States," emphasized the development of traditional manufacturing industries; this appears to be a micro verification aimed at resurrecting previous U.S. government strategies. In addition, when compared to the innovation strategy of the U.S. and the German "Industry 4.0" strategy, China's "2025 Chinese Manufacturing" appears to be a deliberate and positive response.

2.5 The Process Model of TME

Here, the TME process model is completely different from the tech mining process (Porter and Cunningham 2005; Porter 2007). Based on the philosophy of software engineering and considering the environmental analysis requirements and challenge of strategic decision-making in addition to the characteristics of tech mining activities, a "top-down" process model of TME is proposed, which comprises the following steps or phases.

First, to explore the optional solutions for organizational strategy, the TME team should take planning of FIP and sustainable development as the goal and create a detailed analysis of the organization's strategic environment and current status.

Second, according to the strategic plan and options, the team should formulate a detailed implementation schedule for tech mining, choose the correct methods, techniques and tools, and establish an evaluation mechanism for milestones and stage outputs.

Third, tech mining activities should be implemented, including technical monitoring, competitive intelligence collection, technology forecasting, technical opportunity analysis, technology road mapping and intellectual property strategy analysis.

Finally, aiming at the outputs of tech mining activities, a comprehensive evaluation of the strategic planning proposal should be developed based on multiple objective decision making, multiple attribute decision making, etc., from which the optimal solution/s should be selected. The "top-down" process model is presented in Fig. 2.2.

In Fig. 2.2, the TME process is divided into four phases; in the third phase, traditional tech mining processes, methods, techniques and tools can be embedded into the framework of TME. The selected methods and tools used in different phases of TME are shown in Table 2.4.

Table 2.4 implies that TME is typically an interdisciplinary undertaking comprising strategy planning, innovation management, computer science, tech mining,

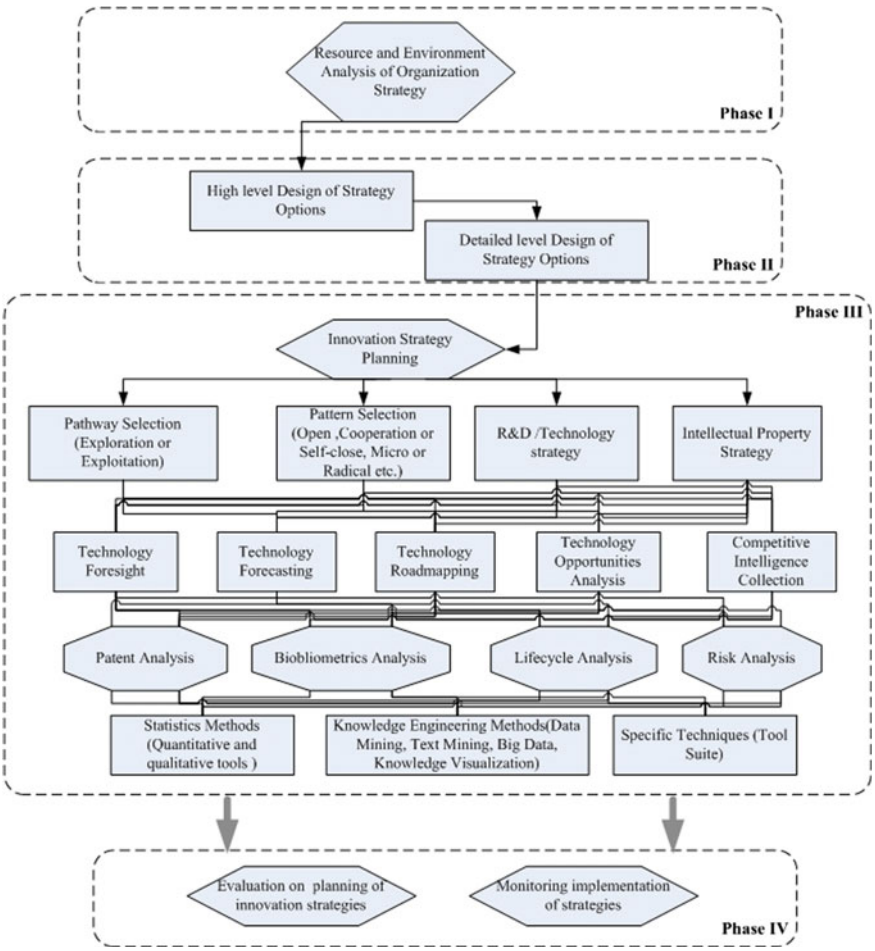

Fig. 2.2 Top-down model of TME process

performance evaluation, quality control and management, among other disciplines. In addition, these four phases represent a prototype only; each phase can be extended to a more concrete process containing detailed steps under technical standards. In phase III, most of the techniques and tools of tech mining are deliberately separated into independent components, although they should be implemented as an integrated methods framework in the tech mining processes (Porter and Cunningham 2005). For example, collecting competitive intelligence is often facilitated by technology road mapping, technology foresight and technology opportunity analysis (Salles 2006; Trumbach et al. 2006; Roberta 2008; Shi et al. 2010; Shin and Lee 2013; Newman et al. 2013; Noh et al. 2015). However, these tech mining techniques can be implemented as components to bring the flexibility and scalability of the engineering framework to the analysis process, and the

Table 2.4 Analytical methods and tools used in different phases of the TME framework

	Description	Theory/ methodology	Tools	Input	Output
Phase I	Requirement analysis	Strategy analysis theory	PEST, SWOT, etc.	Current organizational situations	Report of resources and environmental analysis
Phase II	Design of optional strategy solutions	Strategy planning and management	Five Forces Model, BCG Matrix, Mckinsey7S Model, etc.	Outputs of Phase I	Optional strategy solutions
Phase III	Innovation strategy planning	Innovation strategy management	Innovation management tools, computer science, tech mining techniques and tools	Outputs of Phase II	Planning solutions for organizational innovation strategy
Phase IV	Evaluation and monitoring	Performance evaluation and quality monitoring	Quality and performance evaluation and monitoring tools (Balanced Scored Card, Cause-effect Analysis)	Outputs of Phase III	Reports of evaluation and improvement policies

practice of tech mining can utilize different combinations of techniques and tools and even different processes (Porter 2007) in phase III of TME.

In terms of the outputs of TME, technology road map (TRM) is a definitely crucial product because of the value of decision support for the planning of FIP, and the other strategic management activities (Yu et al. 2015). Based on the strategic decision-making on FIP, innovation pattern, the guidance for R&D and technology management, product and service innovation, marketing tactics and so on could be figured out.

2.6 The Quality Assurance Mechanism of TME

In terms of engineering, the QA (Quality Assurance) mechanism is a critical element. The QA mechanism is derived from the traditional philosophy of product quality. To improve and control product quality, researchers, managers and engineers designed a variety of frameworks, methods and tools for quality management, such as TQC (Total Quality Control), the PDCA (Plan-Do-Check-Action) Cycle, QFD (Quality Function Deployment), Six-Sigma (6σ) Management, and so on.

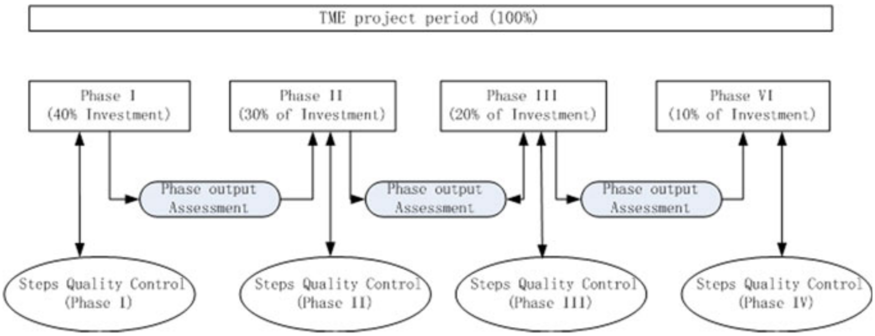

Fig. 2.3 The quality control process for TME projects

Although the output of TME appears to be similar to a service product, the final strategic solution or suggestions should be taken as a concrete product; therefore, traditional theories of product quality management could be better references. Compared with consumer products such as electronics or even software, however, the quality of the TME product cannot be detected or revealed in the short run. In fact, most performance management tools focus on the implementation of strategy, e.g., CSP (Corporate Social Performance), EVC (Economic Value Added) or the BSC (Balanced Score Card). It is difficult to accurately measure strategic quality due to the lack of uniform and convincing metrics and methods. Generally, the basic philosophy and methodology of TQC, PDCA, and Lean Production/ Management are very helpful in TME quality control. Based on the traditional methodology of quality management, the mechanism of phase quality control in TME is designated LTM (Lean Tech Mining). In LTM, the quality control mechanism is defined as embedded double chains, as shown in Fig. 2.3.

Figure 2.3 shows that LTM relies on the naïve quality control philosophy, i.e., the quality assurance of each step in each phase of the TME project is utilized to guarantee the total quality. Although allocating investment to the TME project would cause debate, TME is different from the tech mining process. In a TME project, the organization's strategic requirement analysis and the design of strategy options appear to be more important than the process of tech mining itself. LTM clearly references the core philosophy of software engineering.

2.7 A Suggestion to Improve the Architecture of Innovation Strategy Based on TME

Traditional strategy management, especially innovation strategy planning within organizations (nations, industries and enterprise) typically utilizes one or several tech mining techniques. At the level of architecture, however, there is an obvious gap between strategy management and tech mining. On the basis of TME, tech mining should be integrated into the architecture of innovation strategy, even strategy campaigns for the entire organization. In other words, if the organization strategy campaign is macro engineering (project), TME could be an important sub engineering method (project). The use of TME may be highly significant for the improvement of organizational strategy architecture.

Obviously, the conceptual framework of TME addressed in this paper is only a beginning of the related research and applications, especially for those interdisciplinary studies between innovation strategy and technology analysis and management.

2.8 Discussion

Obviously, because of the high uncertainty, the planning of future innovation pathway is a typically complicated engineering for any organization in macro, industrial and micro level, especially for those SMEs. Tech mining is an emerging tool of technology management. It integrates many techniques and methods of technology analysis; and technology road map is the critical important output of tech mining. To reduce the risk of the high uncertainty in future innovation development, and enhance the delivery performance of tech mining, a conception framework of tech mining engineering is proposed.

Based on the traditional tech mining process model, a new engineering framework named TME (Tech Mining Engineering) is advanced and illustrated in this paper. TME is a natural philosophical and methodological approach to engineering tech mining, which comprises many different techniques and tools deriving from computer science, information processing, competitive intelligence, strategy management, and so on. TME is not a wholly new concept in that there are many related activities and campaigns for innovation strategies, especially at the national and industry levels. These organizations (whether at the macro, industry or micro level) must use the techniques and tools of tech mining frequently in planning future innovation pathways and developing their innovation strategies; however, the conceptual framework of TME remains valuable and significant for several reasons.

First, TME could enhance the interactions between innovation strategy and tech mining techniques and tools.

Second, the proposed framework of TME could facilitate the creation of a new framework of engineering science by integrating several faculties.

Third, the TME framework describes a promising research area with enormous market potential. Although innovation strategy is important for organizations, the implementation of tech mining appears to be a sophisticated and complicated task, and many potential consumers, especially SMEs, would benefit from the guidance of a professional team.

Although entrepreneurs rarely know whether the macro or industrial strategies related to innovation and technology development are optimal when they are first implemented, R&D and technology development could be critical to the survival of enterprises, regardless of whether a firm is an industry leader or a well-known MNE. The failures of firms like Kodak, Motorola, and Nokia derived from many factors, one of which is technology innovation strategy. The stories of these firms show that even industry giants cannot guarantee the success of their technology strategies. SMEs therefore need professional tech mining services to aid in the planning and implementation of innovation and technology strategies. The interesting question is where and how can SMEs gain access to high-quality services related to tech mining. In the current cell phone market, inverse to the failure of Motorola and Nokia, Korea's Samsung created the "Samsung miracle," succeeding in becoming the biggest cell phone manufacturer in the global market by transcending Nokia, Ericsson, Motorola and other firms. This miracle derived from an enterprise that was bankrupt in the 1990s. In addition, it is questionable whether Apple's strategy of "micro innovation" is a good pattern for other companies, especially MNEs, or if it is only applicable to Apple. Seeking to address these questions on the innovation strategies of different organizations, the TME framework proposed in this paper may be unable to provide the right answer directly, but it is valuable and helpful for us to find the best approaches to improve the processes and activities of tech mining under the basic philosophy of engineering management.

The conceptual framework of TME discussed in this paper is only a skeleton and many details can be elaborated upon in future research. For example, the phases of TME are defined in this conceptual framework, but the concrete steps to be taken in each phase, the format and content of each step's outputs, the means of evaluating these outputs, the measurements and metrics of quality and the exploitation of the latest technologies all require further exploration. Even so, TME describes a novel and promising area of research and application.

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