# Methods and Tools Applied in Strategic Technology Planning

**Yulianto Suharto and Tugrul Daim**

**Abstract** The relationship between strategic technology planning and the overall business strategy has been one of the growing fields that attract much interest both from academic and industry points of view. The increasingly important role that technology plays in today's business success is well established. The ability to create, modify and maintain the alignment of technology planning to the overall business strategy—as market/business conditions change, new opportunities arise, and new capabilities are developed—can define the success or failure in the market. An increasing number of studies have been carried out over the years, contributing to the development of strategic technology planning literature. However, there has been no effort made to present an overview of the methodologies and tools that have been cited in technology planning literature. This chapter surveys technology plan development using literature review and classification of articles from 1970–2010 with keyword index in order to explore how technology planning methodologies and applications has developed in this period. The main content of the chapter is related to the works published in leading international journals that involve certain research methodologies or techniques.

## 1 Introduction

Strategic technology planning is an important area and critical in business. It requires a company to utilize its core competences to outperform its competitor. The ability to create, modify and maintain the alignment of technology planning to

Y. Suharto · T. Daim (✉)
Engineering and Technology Management, Portland State University,
SW Fourth, Portland 97201, USA
e-mail: tugrul@etm.pdx.edu

Y. Suharto
e-mail: ysuharto@gmail.com

T. Daim et al. (eds.), *Research and Technology Management in the Electricity Industry*, Green Energy and Technology,
DOI: 10.1007/978-1-4471-5097-8_1, 

the overall business strategy—as market/business conditions change, new opportunities arise, and new capabilities are developed– can define the success or failure in the market [1, 2, 3].

Although strategic technology planning has been developed over the past four decades and found its value in many strategic technology related problems, there is a tremendous effort from scholars in finding more effective methods. This chapter is an effort to capture those developments.

In this chapter the journal articles are reviewed with a particular interest in identifying what approaches, methods, and tools have been presented or employed in strategic technology planning research. An index search for strategic technology planning related articles was carried out in the leading journals of the field of management of technology (MOT). These journals were selected based on the two articles that studied the citations of leading journals most cited in the MOT literature [4], such as Technological Forecasting and Social Change, International Journal of Technology Management, and IEEE Transactions on Engineering Management. An important point that needs to be considered is that this chapter aims to capture all methods and tools applied in strategic technology planning that relates to overall business strategy.

The research method of this chapter is deep analysis of available literature of related fields based on a deductive approach and a content analysis method. The literature survey is based on a search for the keyword index 'technology planning' on the Business Source Premier, Compendex/Engineering Village online database and Proquest database, from which 21,148 articles from 1970–2010 were found on March 1 2011.

After topic filtering, there were 3662 articles related to the keyword 'strategic technology planning methodologies and frameworks' and 249 of these were connected to the keyword 'strategic technology planning methodologies and corporate strategy'. Out of the 249 reviewed articles, 76 are cited in this chapter. Based on the scope of 76 cited articles, this chapter surveys and classifies strategic technology planning methodologies using three categories: market analysis approach, technology analysis approach and combined approaches of market and technology.

## 2 Defining Strategic Technology Planning

Strategic technology planning is defined as the process of determining which technology is not yet adopted that will have a strategic impact on the company. Strategic technology planning is becoming more critical with the rapid development and obsolescence of the technologies. Most companies are facing an increasing and fiercer competitive challenge due to globalization. Basically, there are two reasons behind this phenomenon. First, competition is caused by other companies operating more effectively. Second, the company lost its competitive advantages by cutting back its research and development investments.

Strategic technology planning represents all capabilities that require investment or alignment to achieve the key product attributes defined in the product strategy. These technologies or capabilities come from either internal development or external sources. The specific architecture of this section will depend on how technology is managed in the business, whether by cross-business technology platforms or by business/product-specific technology groups [3].

Strategic technology planning activities–within a corporate level–are often implemented by applying integrated planning instrument, which allow firms to consider both technology-oriented and product-oriented aspects [5].

The literature of strategic technology planning is considered relatively rich at the corporate level [6]. However, dealing with all dimensions and elements of corporate strategy is not the aim of this chapter. For the purpose of this chapter, the literature review and its content analysis will be divided into three categories; market analysis approach, technology analysis approach and combined approaches of market and technology.

## 3 Market Analysis Approach

From the market standpoint, scholars have been conducting several valuable researches in an attempt to formulate methodologies or frameworks for strategic technology planning. Figure 1 described the number of publication lists on strategic technology planning in regards to market analysis approach.

*The experience curve* is one of the well-known approaches in technology planning. The experience curve states that the more frequent a task is performed; less time would be required on subsequent iterations [7]. The reason for why experience curve effect applies, of course, is the complex processes of learning

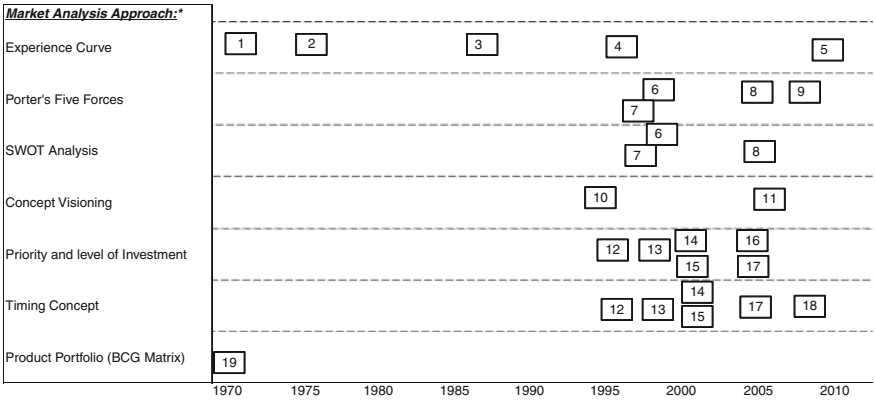


**Fig. 1** Publications on strategic technology planning: market analysis approach (in order of publication time)

involved. The consequences of the experience effect for businesses have been examined by many marketing strategist. They concluded that because the relatively low cost of operations is a very powerful strategic advantage, firms should capitalize on these learning curves. The reason is increased activity leads to increased learning, lower costs, lower prices, increased market share, and eventually can increase profitability and market dominance [8–12].

*Porter's Five Forces* is a framework for industry analysis and business strategy development introduced by [13]. This framework identifies and analyzes five competitive forces that shape every industry, and helps determine an industry's weaknesses and strengths, which include: (1) competition in the industry, (2) potential of new entrants in the industry, (3) power of suppliers, (4) power of customers, and (5) Threat of substitute products. Porter's framework is an extension to the more generic framework on SWOT analysis, a technique that is credited to Albert Humphrey [14–16].

Passey et al. [17] worked with the term *concept visioning* coupled with multiple *scenario building* as part of an innovation roadmap in the technology planning framework. Both terms were utilized to formulate product innovation and to provide effective communication with the required stakeholders. Passey et al. [17] also argues that these tools are necessary to identify the market context, including varying and emerging markets and build the business case to justify resources for further development [17, 18].

Friar [19] argues that strategic technology planning should include: selection, resource allocation and organizing technological assets, which support long-term strategic direction of the company. Based on the work of Christensen [20], Hax and Majluf [21], and Coombs and Richards [22], technology planning can be seen as a tool for:

1. providing overall strategic guidance of the corporate technology base and innovative efforts,
2. providing parenting value to divisions and business units in their innovative efforts,
3. assuring a proper balance and alignment between short-term, incrementally innovative efforts (exploitation) and long term explorative efforts; and
4. Increasing horizontal technology transfer and sharing, as well as synergy and coordination in research and technological innovation between divisions and business units.

These arguments also meant that strategic technology planning—in relation to market analysis—has to deal with the concept of *level of investment involved* [20, 21, 23, 24] and *timing concept* [20, 21, 23, 25–27].

*Market portfolio*—also known as product portfolio [28]—analysis is probably one of the most widely used tools in the field of strategic technology planning with main concern on the market side. This concept was developed since diversified companies were facing two major problems at that time: (1) increasingly complex strategic technology planning process; (2) competition becomes fiercer than ever. Therefore, companies had to find new ways to assure an effective and efficient

**Table 1** List of author(s) as indicated in Fig. 1

| No | Authors | No | Authors |
|---|---|---|---|
| 1 | Gates and Scarpa [8] | 11 | Passey et al. [17] |
| 2 | Ebert [11] | 12 | Hax and Majluf [21] |
| 3 | Globerson and Millen [12] | 13 | Christensen [20] |
| 4 | Hanakawa et al. [10] | 14 | Christensen [25] |
| 5 | Plaza et al. [9] | 15 | Edler et al. [23] |
| 6 | Menon et al. [14] | 16 | Larsson [24] |
| 7 | Hill and Westbrook [16] | 17 | Pieterse [27] |
| 8 | Phaal et al. [15] | 18 | Grienitz and Ley [26] |
| 9 | Porter [13] | 19 | Ernst et al. [28] |
| 10 | Latham and John [18] | | |

management of the company's resources. The BCG matrix was developed for this purpose and still considered as the most widely known and implemented approach [29, 30].

Number in a box refers to author(s) as listed in Table 1.

## 4 Technology Analysis Approach

Different methodologies and techniques have been developed by scholars in their attempt to manage and plan the company's technology. This chapter categorized those methodologies and techniques into: bibliometric, technology acquisition, organizing of technology management, technology integration, soft system methodology, database tomography, technology development envelope (TDE), patent analysis, and analytical hierarchy process (AHP). The publication list is shown in Fig. 2.

*Bibliometric* methods are utilized by Kostoff and Schaller [31–33] to explore the development of strategic technology planning on roadmapping foundation [3]. Hax and Majluf [21] demonstrated that technology planning decisions are not solely based on selection, resource allocation and organizing technological assets. Technology planning also discusses *technology acquisition* methods [20, 25, 34, 35], technology intelligence, technology organization and managerial infrastructure; and timing of technology introduction [20, 23, 26].

The use of *Soft System Methodology* (SSM) in the area of technology planning is well documented. SSM was originally developed in the late 1960s at the University of Lancaster in the UK [36, 37]. At first, it was seen as a modeling tool, but in later years it has been seen increasingly used as a meaningful learning development tool. In combination with technology roadmapping methods, Okutsu et al. [38] managed to apply the combined method into the area of technology planning and implement it to engineering laboratory's application.

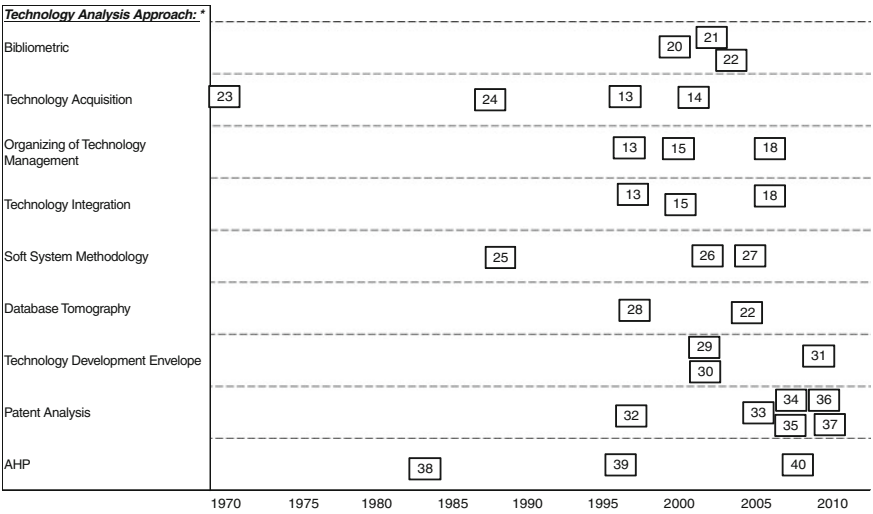


**Fig. 2** Publications on strategic technology planning: technology analysis approach (in order of publication time)

*Database Tomography* (DT) is a patented system for analyzing large amounts of textual computerized material [33, 39]. DT is a textual database analysis system consisting of two major components: (1) algorithms for extracting multi-word phrase frequencies and phrase proximities (physical closeness of the multiword technical phrases) from any type of large textual database (2) interpretative capabilities of the expert human analyst [33].

*Technology Development Envelope* (TDE) method is applied for identifying the optimum path in developing a technology roadmap in which technology strategies and business strategies are combined [40, 41]. The combination of Delphi method and hierarchical decision (AHP) is used as a foundation for building the TDE concept [41, 42].

*Patent analysis*—also known as technology portfolio [28]—could also be implemented in the strategic technology planning on the foundation of technology roadmapping and technology forecasting [43–47]. Yoon [43] and Huang [48] had shown that even though the patent analysis is a powerful technique in technology planning, it is not yet clear whether the analysis is applicable to technology planning—on the foundation of roadmapping and forecasting—over all industries. This condition is a result of different strategies among companies in protecting their innovation. Due to divergence between the use of patents versus. trade secrets according to the characteristics of industries, patent analysis might be inappropriate to some industries.

*Analytical Hierarchy Process* (AHP) is one of the most well known methods in the area of technology planning [42, 49]. AHP is a comprehensive approach to decision making in a complex system. The basic rule in AHP is to decompose

**Table 2** List of author(s) as indicated in Fig. 2

| No | Authors | No | Authors |
|---|---|---|---|
| 13 | Christensen [20] | 29 | Gerdsri [76] |
| 14 | Christensen [25] | 30 | Gerdsri and Kocaoglu [41] |
| 15 | Edler et al. [23] | 31 | Kockan et al. [40] |
| 18 | Grienitz and Ley [26] | 32 | Liu and Shyu [46] |
| 20 | Kostoff and Schaller [31] | 33 | Lee et al. [44] |
| 21 | Kostoff et al. [32] | 34 | Yoon [43] |
| 22 | Kostoff et al. [33] | 35 | Chun et al. (2008) |
| 23 | Jantsch [35] | 36 | Lee et al. [45] |
| 24 | Clarke and Christopher [34] | 37 | Huang and Li [48] |
| 25 | Checkland [37] | 38 | Kocaoglu [50] |
| 26 | Okutsu et al. [38] | 39 | Zhong and Ohsuga [49] |
| 27 | Will [36] | 40 | Gerdsri and Kocaoglu [42] |
| 28 | Kostoff et al. [39] | | |

decision problem into a hierarchy of more easily comprehended sub-problems so each of the sub-problems can be analyzed mathematically and independently [50].

Number in bracket refers to author(s) as listed in Table 2.

## 5 Combined Approaches of Market and Technology

During categorizing all methodologies and approaches in the area of technology planning, we found some other methodologies that are considered to fall into a combination of market and technology approaches. These methodologies include: *change management approach* [51, 52], *synergy making and horizontal technology strategy* [21, 25, 53], *level of acquisition strategy* [20, 21, 23, 25, 54], *technology leakage control* [23], *human resources approach* [27], *scenario planning* [55–58], *cost of innovation* [59], *flexible planning logic* [60], *axiomatic design approach* [61], *innovation matrix* [62], and *technology audit* [63].

*Integrated portfolio*, proposed by Ernst et al. [28], is a combination approach of market and technology portfolio. This approach is developed based on the assumption that pure technology or market portfolios have a one-sided focus on either technology or product market. New technologies have to fulfill market needs to avoid them failing in the market. Integrated portfolio concept is trying to overcome this shortfall by combining market and technology analysis.

Integrated portfolio can be a powerful tool for strategic technology planning purposes because it offers an efficient and effective way to better align market and technology being developed in R&D. Integrated portfolio combines a widely known and used market portfolio concept with a patent portfolio capturing technological aspects [28].

Number in bracket refers to author(s) as listed in Table 3.

**Table 3** List of author(s) as indicated in Fig. 3

| No | Authors | No | Authors |
|---|---|---|---|
| 12 | Hax and Majluf [21] | 44 | Li et al. [56] |
| 13 | Christensen [20] | 45 | Strauss and Radnor [55] |
| 14 | Christensen [25] | 46 | Yamashita et al. [58] |
| 15 | Elder et al. [23] | 47 | Pagani [57] |
| 17 | Pieterse [27] | 48 | Bigwood [59] |
| 19 | Ernst et al. [28] | 49 | Spath and Agostini [60] |
| 40 | Gerdsri and Kocaoglu [42] | 50 | Koc and Mutu [61] |
| 41 | Zhong and Ohsuga [49] | 51 | Groenveld [62] |
| 42 | Lenz [53] | 52 | Martino [63] |
| 43 | Macapanpan [54] | | |

# 6 Analysis and Discussion

## *6.1 Strategic Technology Planning Approaches Before and After the 1980s*

There is a number of interesting facts based on the Figs. 1, 2, 3 to be analyzed. This chapter observed two distinct groups on the approaches of strategic technology planning, before the 1980s and from 1980s until the present. Before the

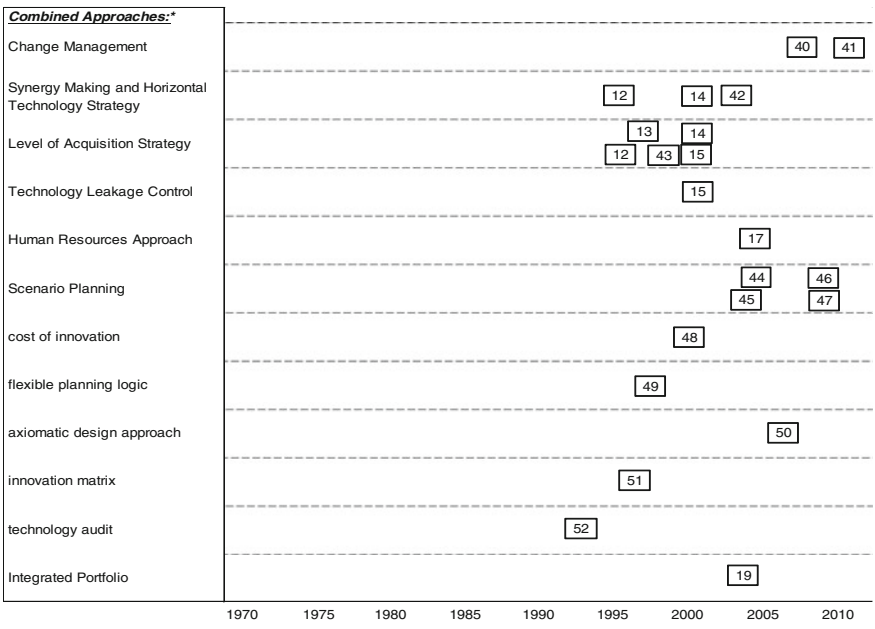


**Fig. 3** Publications on Strategic Technology Planning: Combined Approaches (in order of publication time)

1980s, the number of publication was much smaller, with the focus of approaches on the market side. Among those approaches, the most widely used was the very well-known method called BCG growth matrix, developed in the early 1970s, which is still applicable to today's business condition. During that era, many companies approached their strategic technology planning with heavy emphasis on marketing side (market pull strategy) as their competitive advantages.

The second group, which is much bigger in quantity, arose and developed in the era of mid 1980s until the present, as shown in Figs. 1, 2 with the focus on both market and technology sides. The technology side gained more attention during this period as shown by the publication number. This is understandable since embedding technology planning—as a part of technology management—into overall business strategy has gained a lot of attention both to academicians and practitioners. There are two major reasons for this phenomenon.

First, since the mid 1980s, the subject area of strategic technology planning has grown a significant interest both for scholars and practitioners as a consequence of rapid technological change. This change has attracted many scholars to explore different approaches, models and methodologies, whether for academic purposes only or industrial application purposes. While on one hand this is a reflection of the richness, diversity and relevance of the field, on the other it demonstrates a comparative conceptual weakness in terms of the lack of a common theoretical base to which all contributions may be referred [64].

Second, the internet was opened to general users in the late 1980s or early 1990s and this new era of information and communication technology has played an important role not only in electronic commerce, but also in the flow of information and data. Accessible online journal database has shortened the time for scholars and business practices to get information to support their research and then modify and implement the knowledge for their own purposes.

This chapter also noted an interesting development occurring during the 1990s in terms of the approaches and methodologies in strategic technology planning. During that era—as shown in Fig. 3—a number of chapters were published with the emphasis to look at the two sides, market and technology and how to integrate them into overall business strategy. Globalization and advanced technology development that took place in the early 1990s reshaped the competitive business environment. In response to these changes, companies were developing new competitive strategies, which in turn require new global organizational structures to be effectively implemented [65]. These conditions had led academicians and practitioners to explore the ideas of how to manage technology that is beneficial for companies and pursue long-term objectives, an idea that has been debated by all major companies. Over the years, all of them have attempted to address these issues through a variety of approaches. Farrukh et al. [66] indicated that companies perceived and implemented strategic technology planning approaches in various ways. However, a company needs to aware that there is a real risk that solutions based on very different theoretical foundations could have a damaging effect on business operations if implemented simultaneously [64].

## 6.2 Focus of Strategic Technology Planning Approaches

Due to the variability in approaches and contents in each methodology identified on strategic technology planning, this chapter categorized them into three predominant categories; (1) market focus analysis; (2) technology focus analysis; and (3) combination of market and technology. Each category had a different perspective based on the business priorities and the development of certain technologies at that time.

Pure technology or market analysis has a one-sided focus on either technology or product market. On one side, new technologies have to fulfill market needs to avoid them failing in the market (market pull). On the other side, new technology can also be pushed into the market to create a new market or expand the market (technology push). The degree of difficulty in balancing and integrating the two approaches will mainly depend on the environment. High-risk environment such as in emerging technology requires a deep understanding on two major factors: the nature of the changing business environment in the medium to long term; and the capabilities of the company.

Technological considerations need to be addressed in formulating strategic technology planning. These considerations include both external factors, such as the nature of technological change and competition level, and internal factors, such as technological capabilities and business priorities. Technology Management Framework, proposed by Probert et al. [64], described how a company needs to formulate strategic technology planning based on two dimensions, market/commercial perspective and technological perspective. The framework talked about how to incorporate strategy, innovation and operation level into both perspectives.

## 6.3 Challenges in Strategic Technology Planning approaches

While many companies are concerned about how to best align technology resources with business objectives (as market/business conditions change, new opportunities arise, and new capabilities are developed), there appears to be little commonality in the approaches adopted to support strategic technology planning, despite of all the techniques that had been mentioned above. Technology planning tends not to be identified as a specific business process, but rather as embedded within other processes, such as a general strategy and planning, innovation, new product introduction and R&D management [25, 66]. Companies face various challenges developing and implementing technology planning into their existing processes and operations.

In terms of strategic technology planning contents, this chapter is able to identify three issues/challenges in the area of technology planning approaches.

As in any other academic chapters, these challenges are an open door for future research to address them.

First, for all the approaches that have been presented in this chapter, little evidence has been found on how well the methodologies and approaches align technology planning with business performance. A technology scorecard could be utilized to align the technology investment of companies with their business performances.

Second, it is worth noting that all of the approaches analyzed in this chapter—especially the combined approaches—build on the foundation of technology roadmapping [3, 15, 25, 31, 32, 38, 39, 41, 42, 52, 56, 62, 66–74]. The process of technology roadmapping is used by a range of companies to support technology strategy and planning [66].

Third, this chapter also found little evidence of an approach or framework that can align between product technology planning and innovation database through the use of the innovation management database as a tool in technology planning.

## 7 Conclusions, Limitations and Future Research

Strategic technology planning is an important activity across any industry or company types, driven by increasing competition, market requirements, regulation, technology change, company strategy and product/service innovation [66, 74]. Strategic technology planning has gained increasing prominence globally. It has been practiced for some time and academicians and practitioners' interest in the technique has recently picked up and evolved through various stages, with shifts in focus and approaches that is considered to give their companies a competitive edge. Many are looking to develop more formal procedures that would smooth the way for the introduction and implementation of strategic technology planning techniques. Of course, technology eventually will find its way into the workplace, with or without planning. However companies that fall back on a reactive, "as needed" approach in their adoption of new technologies runs the risk of making costly, personality-driven choices, rather than tactical decisions that align with their larger corporate strategy and goals [75].

Some of the ongoing research is concentrating technology planning on the foundation of roadmapping with the purpose to align the technology planning with business performance. The main reason for this is that technology roadmapping is considered to reflect 'all the plans (technology and business performance)' and as such build on rather than replace existing techniques in use within a company [66].

There are a number of limitations to this chapter. First, a literature review for the broad category of strategic technology planning tools and approaches is a difficult task, due to the extensive background knowledge needed for studying, classifying, and comparing these publications. Second, this chapter only reviewed journal literature as the primary source of information, thus does not represent the entire body of strategic technology planning literature.

**Table 4** Knowledge gaps and future research opportunities

| Current issues | Knowledge gaps | Research opportunities |
|---|---|---|
| Aligning strategic technology planning (TP) with business performance (BP) | How to build the framework to link TP to BP?<br>How to measure the output? | Utilizing technology scorecard methodology to measure the output |
| TP on the foundation of technology roadmapping (TRM) | How to find the right TRM approach (customize to each industry/ company) to achieve the BP? | Using more dynamic approach (dynamic TRM) |
| Linkage between desired product-technology planning and innovation database | Need for improved frameworks and tools, with a desire for simple, structured, robust, flexible and integrated tools and processes | Open innovation as TP tool<br>Innovation database management |

Table 4 describes some potential future research based on the current knowledge gaps that this chapter is able to identify.

## References

1. Chandler AD (1962) Strategy and structure: chapters in the history of the industrial enterprises. MIT Press, Cambridge
2. Chen H, Ho JC, Kocaoglu DF (2009) A strategic technology planning framework: a case of Taiwan's semiconductor foundry industry. IEEE Trans Eng Manage 56(1):4–15
3. Whalen PJ (2007) Strategic and technology planning on roadmapping foundation. Industrial research institute, inc. Res Technolo Manag 50:40–51
4. Tran TA, Daim T (2008) A taxonomic review of methods and tools applied in technology assessment. Technol Forecast Soc Chang 75:1396–1405
5. Lichtenthaler U (2008) Integrated roadmaps for open innovation. Res Technol Manag 51(3):45–49
6. Arasti MR, Mahdi K, Noori J (2010) The linkage of technology strategy and overall strategy of multi business. Portland international center for management of engineering and technology. In: Proceedings of the—technology management for global economic growth, pp 22–33
7. McClees CH, Willyard CW (1987) Motorola's technology roadmap process. Res Manag 30:13
8. Gates M, Scarpa A (1972) Learning and experience curves. ASCE J Constr Div 79–101
9. Plaza M, Ngwenyama OK, Rohlf, Katrin (2010) A comparative analysis of learning curves: Implications for new technology implementation management. Eur J Oper Res 200(2):518–528
10. Hanakawa N, Morisaki S, Matsumoto K (1998) Learning curve based simulation model for software development. In: International conference on software engineering, pp 350–359
11. Ebert RJ (1976) Aggregate planning with learning curve productivity. Manage Sci 23(2):171–182
12. Globerson S, Millen R (1989) Determining learning curves in group technology settings. Int J Prod Res 27(10):1653–1664
13. Porter ME (2008) The five competitive forces that shape strategy. Harvard Bus Rev 86–104
14. Menon A et al (1999) Antecedents and consequences of marketing strategy making. J Mark 63(2):18–40

15. Phaal R et al (2005) Developing a technology roadmapping system. In: Procedings of the Portland international center for management of engineering and technology (PICMET). Portland, pp 99–111
16. Hill T, Westbrook R (1997) SWOT analysis: it's time for a product recall. Long Range Plan 30(1):46–52
17. Passey SJ et al (2006) Targeting the innovation roadmap event horizon: product concept visioning and scenario building. In: Proceedings of the IEEE international conference on management of innovation and technology (ICMIT) 604–607
18. Latham JR, John R (1995) Visioning. The concept, trilogy, and process. Qual Prog 28(4):65–68
19. Friar J, Horwitch M (1985) The emergence of technology strategy: a new dimension of strategic management. Technol Society 7(2):143–178
20. Christensen JF (1998) The dynamics of the diversified corporation and the role of central management of technology. DRUID working papers. Aalborg, Denmark
21. Hax AC, Majluf NS (1996) The strategy concept and process: a pragmatic approach. Prentice Hall, Upper Saddle River
22. Coombs R, Richards A (1993) Strategic control of technology in diversified companies with decentralized R&D. Technol Anal Strateg Manag 5:385–396
23. Edler J, Meyer-Krahmer E, Reger G (2002) Changes in the strategic management of technology: results of a global benchmarking study. R&D Manag 2:149–164
24. Larsson A (2005) Technology strategy formation from a resource-based view—booz-allen and hamilton methodology revisited. Int J Intell Enterp 1(1):3–22
25. Christensen JF (2002) Corporate strategy and the management of innovation and technology. Ind Corp Change 2:263–288
26. Grienitz V, Ley S (2007) Scenarios for the strategic planning of technologies: technology scenarios at the early stages of the management of technologies. J Technol Manage Innov 3:21–37
27. Pieterse E (2005) The development of an internal technology strategy assessment framework within the service sector utilizing total quality management principles. South African J Ind Eng 193–244
28. Ernst H, Fabry B, Soll JH (2004) Enhancing market-oriented R&D planning by integrated market and patent portfolios. J Bus Chem 1(1):2–13
29. Hedley B (1977) Strategy and the business portfolio. Long Range Plan 10:9–15
30. Day GS (1977) Diagnosing the product portfolio. J Mark 41:29–38
31. Kostoff RN, Schaller RR (2001) Science and technology roadmaps. IEEE Trans Eng Manag 48:132–143
32. Kostoff RN et al (2004) Disruptive technology roadmaps. Technol Forecast Soc Chang 71:141–159
33. Kostoff RN et al (2005) Power source roadmaps using bibliometrics and database tomography. Energy 30:709–730
34. Clarke CJ (1987) Acquisitions—techniques for measuring strategic fit. Long Range Plan 20(3):12–18
35. Jantsch E (1970) Technological forecasting at national level in Japan. Technol Forecast 1(3):325–327
36. Will B (2005) http://users.actrix.co.nz. http://users.actrix.co.nz/bobwill/ssm.pdf
37. Checkland PB (1988) Soft systems methodology: an overview. J Appl Syst Anal 15:27–30
38. Okutsu S et al (2003) Bringing technology management into the academic science and engineering laboratory: through the fusion of soft systems methodology and technology road mapping. In: Proceedings of Portland international center for management of engineering and technology (PICMET), Portland
39. Kostoff RN et al (1997) Database tomography for technical intelligence: Comparative roadmaps of the research impact assessment literature and the journal of the American Chemical Society. Scientometrics 40(1):103–108

40. Kockan I et al (2009) Application of technology development envelope (TDE) approach for future powertrain technologies: a case study of ford otosan. In: Proceedings of Portland international center for management of engineering and technology (PICMET), Portland, pp 3349–3363
41. Gerdsri N, Kocaoglu DF (2003) An analytical approach to building a technology development envelope (TDE) for roadmapping of emerging technologies: a case study of emerging electronic cooling technologies for computer servers. In: Proceedings of Portland international centerfor management of engineering and technology (PICMET), Portland, pp 380–389
42. Gerdsri N, Kocaoglu DF (2007) Applying the analytic hierarchy process (AHP) to build a strategic framework for technology roadmapping. Math Comput Model 46:1071–1080
43. Yoon B (2008) Patent analysis for technology forecasting: sector—specific applications. In: Proceedings of the IEEE international engineering management conference. Managing engineering, technology and innovation for growth, Europe
44. Lee S et al (2006) Using patent information for new product development: keyword—based technology roadmapping approach. In: Proceedings of Portland international center for management of engineering and technology (PICMET), Istambul, pp 1496–1502
45. Lee S et al (2008) Using patent information for designing new product and technology: keyword based technology roadmapping. R&D Manag 38:169–188
46. Liu SJ, Shyu J (1997) Strategic planning for technology development with patent analysis. Intern J Technol Manag 13(5–6):661–680
47. Wu YC, Lee PJ (2007) The use of patent analysis in assessing ITS innovations: US, Europe and Japan, Transp Res Policy Pract 41(6):568–586
48. Huang L, Li J (2009) Empirical research on technology share based on hybrid approach for morphology analysis and conjoint analysis of patent information. In: Proceedings of 11th international conference on computer modelling and simulation, UKSim, pp 293–298
49. Zhong N, Ohsuga S (1996) A hierarchical model learning approach for refining and managing concept clusters discovered from database. Data Knowl Eng 20:227–252
50. Kocaoglu DF (1984) Hierarchical decision modeling—a participative approach to technology planning. In: Proceedings of the international congress on technology and technology exchange, Pittsburgh, pp 481–482
51. Gerdsri N et al (2008) Applying change management approach to guide the implementation of technology roadmapping (TRM), In Portland International Center for Management of Engineering and Technology (PICMET). Cape Town, South Africa, pp 2133–2140
52. Gerdsri N et al (2010) An activity guideline for technology roadmapping implementation. Technol Anal Strateg Manage 22:229–242
53. Lenz PJ (2004) Bringing corporate level R&D back to life. Masters of Technol Capstones 17
54. Macapanpan T (1999) Private sector activities on research and development. philippine institute for development studies (Published as Discussion Paper), pp 1–58
55. Strauss JD, Radnor M (2004) Roadmapping for dynamic and uncertain environments. Res Technol Manage 47:51–57
56. Li M et al (2005) Making sense of roadmapping practices in dynamic contexts: a knowledge management perspective. In: Proceedings of Portland international center for management of engineering and technology (PICMET), Portland
57. Pagani M (2009) Roadmapping 3G mobile TV: strategic thinking and scenario planning through repeated cross-impact handling. Technol Forecast Soc Chang 76:382–395
58. Yamashita Y et al (2009) Knowledge synthesis in technology development. J Syst Sci Syst Eng 18:184–202
59. Bigwood MP (2000) Applying 'cost of innovation' to technology planning. Technol Forecast Soc Chang 43(3):39–46
60. Spath D, Agostini A (1998) Flexible planning logic for technology planning. J Mater Process Technol 76(1–3):76–81

61. Koc T, Mutu Y (2006) A technology planning methodology based on axiomatic design approach. In: Proceedings of Portland international conference on management of engineering and technology (PICMET), vol 3. Portland, pp 1450–1456
62. Groenveld P (1997) Roadmapping integrates business and technology. Res Technol Manag 40:48
63. Martino JP (1994) Technology audit: key to technology planning. In: Proceedings of the IEEE National Aerospace and Electronics Conference, vol. 2, pp 1241–1247
64. Probert DR, Phaal R, Farrukh CJP (2000) Structuring a systematic approach to technology management: concepts and practice. In: Proceedings of the international association for management of technology (IAMOT), Lausanne
65. Bradley SP, Hausman JA, Nolan RL (1993) Globalization Technology and competition: fusion of computers and telecommunications in the 1990s. Harvard Business School Press, Boston
66. Farrukh CJP, Phaal R, Probert DR (2002) Industrial practice in technology planning—implications for a useful tool catalogue for technology management. In: Portland international center for management of engineering and technology (PICMET), Portland, p 200
67. Kameoka A, Kuwahara T, Li M (2003) Integrated strategy development: an integrated roadmapping approach. In: Proceedings of Portland international conference on management of engineering and technology, Portland, pp 370–379
68. Nauda A, Hall DL (1992) Strategic technology planning–developing roadmaps for competitive advantage. In: Proceedings of 91 Portland international conference management engineering and technology, Portland, pp 745–748
69. Probert D, Shehabuddeen N (1999) Technology road mapping: the issues of managing technology change. Int J Technol Manag 17:646–661
70. Collier DW (1985) Linking business and technology strategy. Strategy Leadersh 13:28–44
71. Specht D (2007) Integration of strategic business planning and technology planning in globally operating companies by means of roadmapping. Int J Technol Intell Plann 3(2):126–140
72. Specht D, Kadlubski A, Behrens S (2007) Integration of strategic business planning and technology planning in globally operating companies by means of roadmapping. Int J Technol Intell Plann 3(2):126–140
73. Metz PD (1996) Integrating technology planning with business planning. Res Technol Manag 39(3):19–22
74. Lichtenthaler U (2008) Opening up strategic technology planning: extended roadmaps and functional markets. Manag Decis 46(1):77
75. Fenn J, Linden A, Fairchok S (2003) Strategic technology planning: picking the winners. Gartner, Inc., Strategic analysis report R-20-3354
76. Gerdsri N (2003) An analytical approach to building a technology development envelope (TDE). In: Proceedings of the Portland international conference on management of engineering and technology (PICMET), Portland, pp 123–135