Assessing Industry Technology Roadmap Development Process

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the requirements for the degree of Doctor of Philosophy

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

____(Signed)

____________________LI SINUO____________________(Name of student)

DEDICATION

This is dedicated to my beloved husband, parents and brother,

without whom none of my success would be possible.

ABSTRACT

Industry technology roadmap (ITRM) is designed to match the current and potential market demands with specific technological solutions for the development of a specific industry. Industry technology roadmapping has been widely applied in various industries including textile, semiconductive energy, and electronic device industries. Various approaches for technology roadmapping have been established based on theories and experiences, but limited research was available to assess ITRMs. To fill the research gap, this study aims to develop systematic and comprehensive methods to assess ITRMs in terms of internal quality and external performance, particularly for the textile industries in different parts of the world. All of the following six objectives were successfully achieved.

(1) An internal assessment model with theoretical framework and detailed measurements was created to systematically assess the internal content quality of an ITRM with quantitative methods.

(2) An external assessment model was established to assess the actual performances based on the real data statistics in terms of the conformance of the actual trends of industrial development within the target period with the original predictions from the ITRM.

(3) The newly developed internal assessment model was successfully applied to four textile industry technology roadmaps in different countries. Detailed measuring methods and steps were demonstrated. The same four roadmaps were successfully evaluated using the newly developed external

assessment model on the basis of actual industrial statistics of their first five years compared with the corresponding predictions in the ITRMs, in terms of their conformance levels.

(4) The relationships between internal quality and external performance of the same four ITRMs were investigated using the collected data. The internal and external assessment models were integrated to a system for ITRM assessment on both the contents and performance. The system provides a possibility to predict ITRM's external performances by internal quality assessment.

(5) The success factors of an effective ITRM, especially for the textile industry, were determined on the basis of assessments and relationships between internal quality and external performance of the four ITRMs.

(6) The development process of an under-developed UK advanced textile ITRM was assessed using the internal assessment model. The author, as a practitioner in that ITRM development team, has made new suggestions and developed an integrated ITRM for the UK textile industry.

This research opens a new chapter in the quantitative assessment of technology roadmaps with a strong theoretical foundation. The future users can apply the proposed models to assess the ITRM's internal quality before application and its external performance after a period of application. For the corporate level, the users may follow the rules and develop corresponding models to systematically assess the corporate technology roadmaps. This research provides practitioners with feasible recommendations for effective technology roadmapping generated from actual case analysis.

OUTPUTS

∗Referred Journal Paper

1. Li, S. N., Li, Y., Yu, W., Hu, J. Y., Liao, X. & Muthu, S. S. (2017). Assessing the Internal Quality of Industry Technology Roadmaps. (Under review)

2. Li, S. N., Li, Y., Yu, W., Hu, J. Y. & Muthu, S. S. (2017). Assessing the Performance of Industry Technology Roadmaps. (In preparation)

∗Referred Conference Paper

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2. Li, S. N., Li, Y., & Cao, M. L. (2016). Current Status of the UK Textile Industry and its Sustainable Development. In Li, Y. & Padhye, R. (Eds.), Textile Bioengineering and Informatics Symposium Proceedings, 2016, Vols 1 and 2 (pp. 756-764).

3. Li, S. N., Li, Y., & Li, M. W. (2014). Analysis of Industrial Value Chains for Biomedical Textile Industry Technology Roadmap. In Li, Y., Xin, J. H., Yoon, K. J. & Li J. S. (Eds.), Textile Bioengineering and Informatics Symposium Proceedings, 2014, Vols 1 and 2 (pp. 177-186).

4. Li, S. N., Li, Y., Li, M. W., Li, Z., Hu, J. Y., Guo, Y. P., Li, J.S. & Cao, M. L. (2013). Development of Technology Roadmap for Guangdong Biomedical Textile Industry. In Li, Y., Yao, M., Gao, Y. & Li, J. S. (Eds.), Textile Bioengineering and Informatics Symposium Proceedings, Vols 1-3 (pp. 1407-1419).

5. Li, S. N., Li, Y., Yao, M., Li, M. W., Li, Z., & Liao, X. (2012). Technology Platforms for Cluster Innovations in Biomedical Textile Industry. In Li, Y., Takatera, M., Kajiwara, K. & Li, J. S. (Eds.), Textile Bioengineering and Informatics Symposium Proceedings, Vols 1 and 2 (pp. 253-266).

∗Conference Speech

1. Li, S. N., Li, Y., & Yu, W. (2017). An Evaluation of Technology Roadmaps in the Textile Industry. Textile Summit 2017, Raleigh.

2. Li, S. N., Li, Y., & Yu, W. (2016). Industry Technology Roadmapping on Biomedical Textiles in China. Textile Summit 2016, Hong Kong.

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Chapter 1 Introduction

Industry technology roadmap (ITRM) is a plan that helps to match current and potential market demands with specific technology solutions for the development of a specific industry. Industry technology roadmapping has been widely used in various industries, including the textile, semiconductive, energy, and electronic device industries. Various approaches for technology roadmapping have been established based on theories and experiences, but limited academic research has been conducted to assess ITRMs. This thesis mainly focuses on the assessment of an ITRM in terms of internal quality and external performance. A brief introduction is presented in the following sections, including the research background, research significance, objectives, research approach, and thesis outline.

1.1 Background

Technology roadmap is a strategic planning tool adopted by various organizations, including corporates, industrial associations, institutions, and the government (Kostoff & Schaller, 2001; Laat & Mckibbin, 2003), for predicting the direction of market demands and technology development to facilitate decision making in the medium to long term (Amer & Daim, 2010). This planning tool maps the evolution and development routine of an investigated system, and it shows the visualized linkages between strategic planning and target development (Phaal et al., 2011). Previous research (Amer & Daim, 2010; Caetano & Amaral, 2011; Carvalho et al., 2013; Galvin, 1998; Jeffrey et al., 2013; Kostoff & Schaller, 2001; Yoon et al., 2008) reported three levels of technology roadmaps: corporate, industry, and policy. This study focuses mainly on the textile industry technology roadmap (ITRM) using visualized strategic planning tool.

As a relatively new methodology of science and technology management, technology roadmapping has its limitations. With the lack of guidelines, focus, and clear boundaries, evaluating the value of technology roadmap and customizing it is difficult (Carvalho et al., 2013). Evaluation of technology roadmaps is urgently needed considering its further widespread application. Various techniques and approaches to roadmapping exist (Garcia, 1997; Lee et al., 2007; Phaal et al., 2001c, 2004), but roadmaps are yet to be evaluated well (Carvalho et al., 2013; Vatananan & Gerdsri, 2012). A small number of scholars assessed the success of corporate-level technology roadmaps, and in most of these studies, the outcome was decided by the users' perception and attitude (Farrukh et al., 2003; Gerdsri et al., 2009; Lee et al., 2012). Recently, a few studies have initiated new assessment perspectives, such as roadmapping process (Gerdsri & Assakul, 2007; Phaal & Muller, 2009), roadmap achievements (Jeffrey et al., 2013), and structuring contents (Gerdsri et al., 2009; Kajikawa et al., 2008). Research on the assessment of internal quality and external performance of an ITRM remains limited.

According to background research, the knowledge gap in the body of literature is a lack of theoretical foundation and practical methods to systematically assess technology roadmaps in terms of content quality and effectiveness.

1.2 Significance

The main task of an effective ITRM is to analyze the current status of the investigated industry and forecast development trends for minimizing the gaps between the market demands and technology development. To systematically assess an ITRM's contents and effectiveness, its value before and after adoption must be evaluated, and practical guidelines for future ITRMs must be provided.

Internal and external assessment models, including theoretical frameworks and assessment methods, are developed to systematically assess the internal content quality and external actual performance of ITRM. The proposed assessment models are applied to four global textile ITRMs, and relevant success factors are generated based on the assessment results.

This research opens a new chapter in the quantitative assessment of technology roadmaps with a theoretical foundation. Users can apply the proposed models to assess an ITRM's internal quality before application and its external performance after a period of utilization. For the corporate level, users may follow the rules and develop corresponding models to systematically assess corporate technology roadmaps. This research also provides practitioners with feasible recommendations for effective technology roadmapping generated from actual case analysis.

1.3 Objectives

To fill the knowledge gaps stated in Section 2.6, the six following research objectives are developed:

O_1: Establish an assessment model to evaluate the internal content quality of ITRMs with quantitative methods.

O_2: Establish an assessment model to evaluate the external performance of ITRMs with quantitative methods.

O_3: Evaluate four global textile ITRMs to investigate the feasibility of the newly-proposed internal and external assessment models.

O_4: Investigate the relationships between internal quality and external performance.

O_5: Determine success factors of an effective ITRM, especially for the textile industry.

O_6: Assess and refine the technology roadmap for the UK advanced textile industry with the proposed assessment methods.

1.4 Research approach

To achieve the research objectives, this study applies various methods and processes correspondingly in each step. First, an internal assessment model, including a theoretical framework and detailed measurement, is created to systematically assess the internal content quality of an ITRM. This model is adopted to assess the internal qualities of four global textiles ITRMs, with the content analysis method and quantitative analysis approach. Second, an external assessment model is established to assess the actual performance of an ITRM by examining the conformance between the ITRM predictions and actual industrial development trends in the targeted period. The ITRMs for internal assessment are also evaluated based on their external performance through data collection, conformance investigation, and quantitative analysis. Third, the relationship between the internal quality and external performance is also investigated using correlation analysis and scatter diagrams. Fourth, the success factors of an effective ITRM, tailored for the textile industry, are determined based on the internal and external assessments of the four textile ITRMs and the relationships between internal quality and external performance. Finally, an action research on technology roadmapping in the advanced textile industry in the UK is summarized with the proposed success factors and assessed with the proposed model as a practical application. A detailed explanation of the research approach is presented in Chapters 3 to 6.

1.5 Thesis outline

This thesis is composed of seven chapters. The introduction is presented in Chapter 1, followed by a detailed literature review in Chapter 2 that reviews existing studies on industry technology roadmap and roadmap assessment and addresses the knowledge gaps to be filled. The internal assessment model is introduced in Chapter 3, from its theoretical foundation to specific measuring methods, and an application of the model is illustrated to assess four global textile ITRMs. The external assessment model, along with theoretical framework, detailed measuring methods, and its application to the four textile ITRMs, is presented in Chapter 4. Based on the assessment results of the four ITRMs, the relationship between internal and external assessments is investigated in Chapter 5. The summary and internal quality assessment of technology roadmapping in the advanced textile industry in the UK is presented in Chapters 6. The conclusion is stated in Chapter 7. A flowchart of this thesis is summarized in Fig. 1.1.

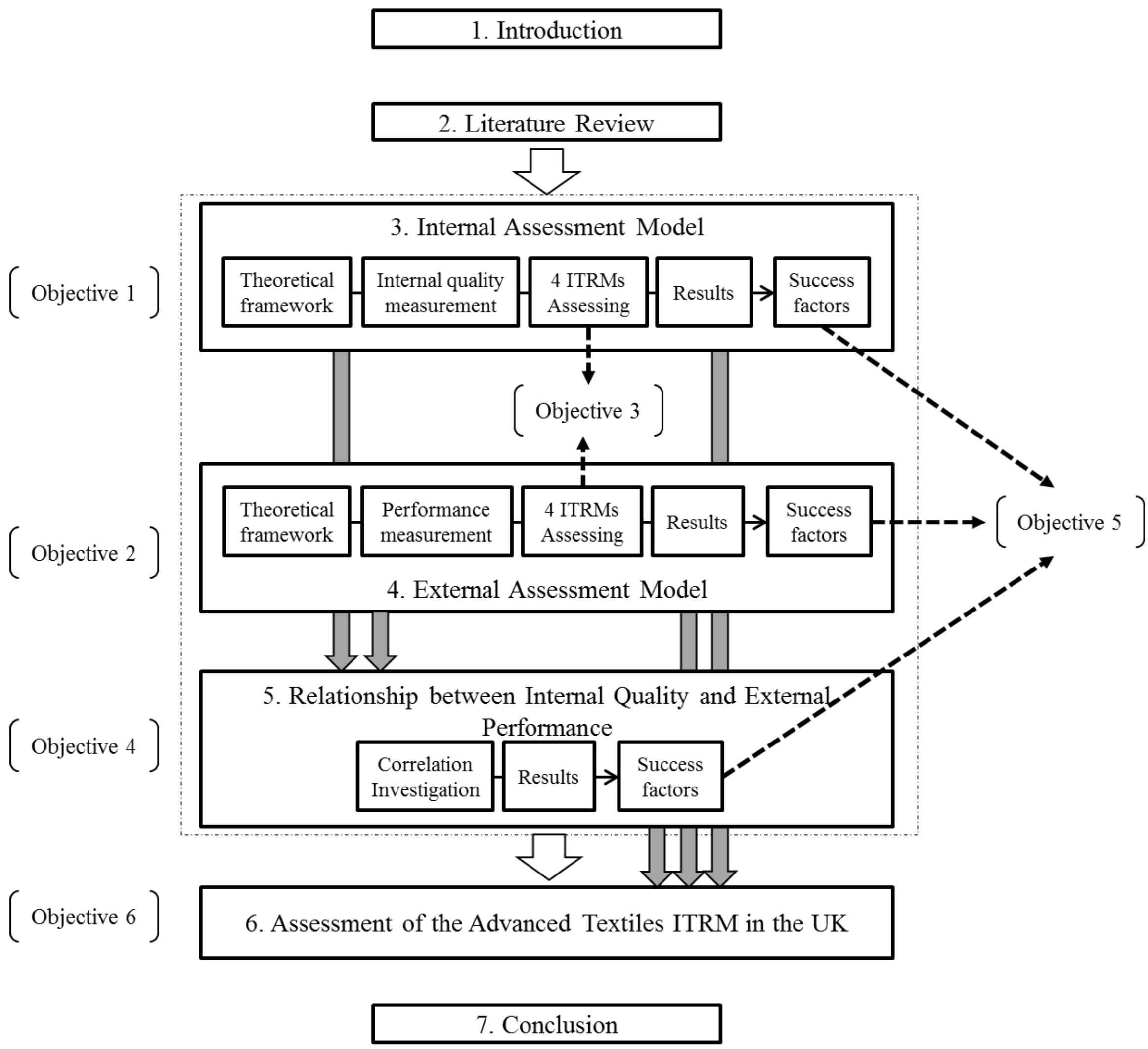


Fig. 1.1 Flowchart of thesis

Chapter 2 Literature Review

Since Motorola's technology roadmapping was first developed in 1987, technology roadmapping has evolved as a scientific methodology for strategic planning and technology management (Willyard, 1987). Thereafter, a growing number of articles about method developments and practical applications of technology roadmapping have been published (Allan et al., 2002; EIRMA, 1997; Galvin, 1998; Kostoff & Schaller, 2001). With the wide spread of technology roadmapping within various organizations in different areas, the assessment methods for technology roadmaps have been addressed as one of the key research gaps in the literature (Carvalho et al., 2013; Vatananan & Gerdsri, 2012). To better provide a comprehensive background for the present research, a review of technology roadmapping methodology and applications are provided in the following sections.

The review begins with various descriptions and categories of technology roadmapping, followed by the methodologies and applications of technology roadmaps for corporates, industries, and policymaking. The assessments of technology roadmaps in the global textile industry and success factors are also reviewed.

2.1 Descriptions of technology roadmap

Technology roadmap has been gaining recognition from the industries, academia, and governments, and various experts offered different descriptions of this planning tool. A roadmap refers to the extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field. Roadmaps communicate visions, attract resources from business and government, stimulate investigations, and monitor progress (Galvin, 1998). Science and technology roadmap is a visualized and persuasive picture of future science and technology landscape for decision making (Kostoff & Schaller, 2001). The crucial features of roadmaps are related to visualization and communication regardless of how a "roadmap" is defined (Yoon et al., 2008). A roadmap is a communication and planning tool to predict the direction of market demands and technology development and conduct medium- and long-term decision making (Amer & Daim, 2010).

The description by Amer and Daim is more appropriate in the present research. "Technology roadmap" in this research refers to a visualized strategic planning and industrial chain communication tool to forecast the industrial trends from market and technology dimensions and make decisions for development in the next ten to twenty years so as to match the market demands with the technology and innovation advancement.

Technology roadmapping is used to describe the creation of a technology roadmap. Technology roadmapping is the contextual process for roadmap development, communication, revision, and update (Li & Kameoka, 2003). This process is a technique for technology management; strategic planning and relationship exploitation; and communication between technological resources, organizational objectives, and dynamic environment (Phaal et al., 2004).

2.2 Categories of technology roadmaps

Technology roadmap is a planning and communication tool to map the future directions for the industry, academia, and government. The following categories of technology roadmaps have been proposed in various versions:

a) Roadmaps are classified into four types, including science and technology, industry technology, corporate or product-technology, and product/portfolio management roadmaps (Kostoff & Schaller, 2001).

b) Technology roadmap approach features three levels: firm, industry, and policy levels (Costa et al., 2005; Phaal, 2010).

c) Based on the characteristics of the organizational processes, technology roadmaps are divided into multi-organization and single-organization roadmaps (Jeffrey et al., 2013).

d) Technology roadmaps can either be a market-pull or technology-push type (Caetano & Amaral, 2011; Lee et al., 2009a; Probert et al., 2000).

2.3 Methodology and application of technology roadmap

In this chapter, the methods of technology roadmaps are reviewed at three levels: corporate, industry, and policy levels. This research focuses on industrial roadmaps.

2.3.1 Corporate-level technology roadmap

Technology roadmap is one of the most popular strategic planning and communication visualized tool at the corporate level (Albright & Kappel, 2003; Panapanaan et al., 2003; Phaal et al., 2013). The following subsections present the applications and practices of three main models that contributed greatly to the development of technology roadmaps for corporates.

2.3.1.1 EIRMA model of delivering business vision

In 1997, the European Industrial Research Management Association (EIRMA) proposed a concentrated framework for technology roadmap (EIRMA, 1997), which has been widely considered as the fundamental model for later development. Fig. 2.1 shows that EIRMA depicted three layers of technology roadmapping. Based on the timeline, specific technology, skills, competencies, and resources are prepared (bottom layer) for developing the new products, service, capability, and systems (middle layer), which cater for the business or market (top layer).

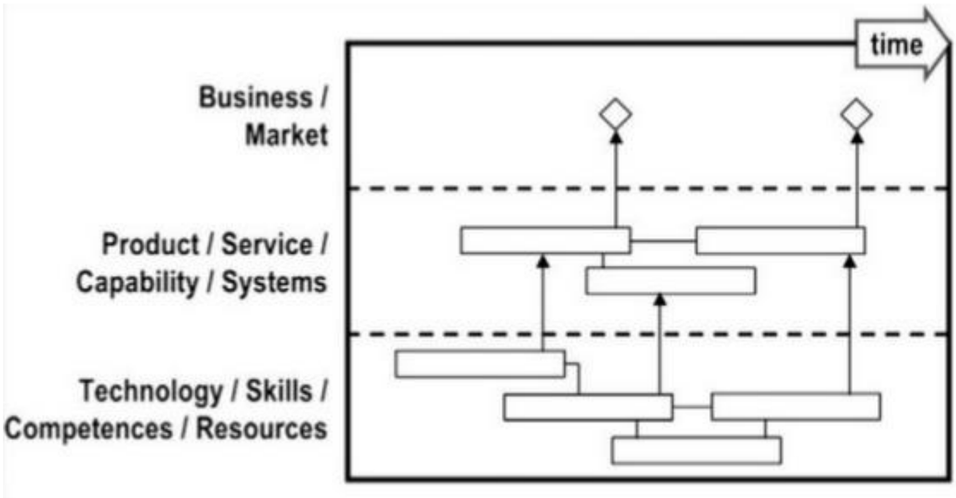


Fig. 2.1 Technology roadmapping framework by EIRMA (EIRMA, 1997)

This framework clearly illustrates the development flow from technology/skill to product/system to the market, and these layers are adopted as the key attributes for assessing the technology roadmaps in this thesis. However, the framework lacks the relationship between technology and market. The power of market forces toward the development of product and technology must be evaluated.

2.3.1.2 Probert and Shehabuddeen model for new technology change

Technology roadmap is also described as a key management tool in formulating the link between technological resources and exploiting market opportunities (Probert & Shehabuddeen, 1999). After developing and implementing technology roadmaps in three companies in the fields of aerospace components, steelmaking, and electronics, Probert and Shehabuddeen (1999) proposed a generic framework for mapping technology change for corporates that focused on the manufacturing process.

During strategic technology planning (see Fig. 2.2), the first step is to analyze the market information and identify the technology available. The second step is to make product-market analysis and technology assessment. The final step is to generate product-technology option evaluation for creating roadmaps.

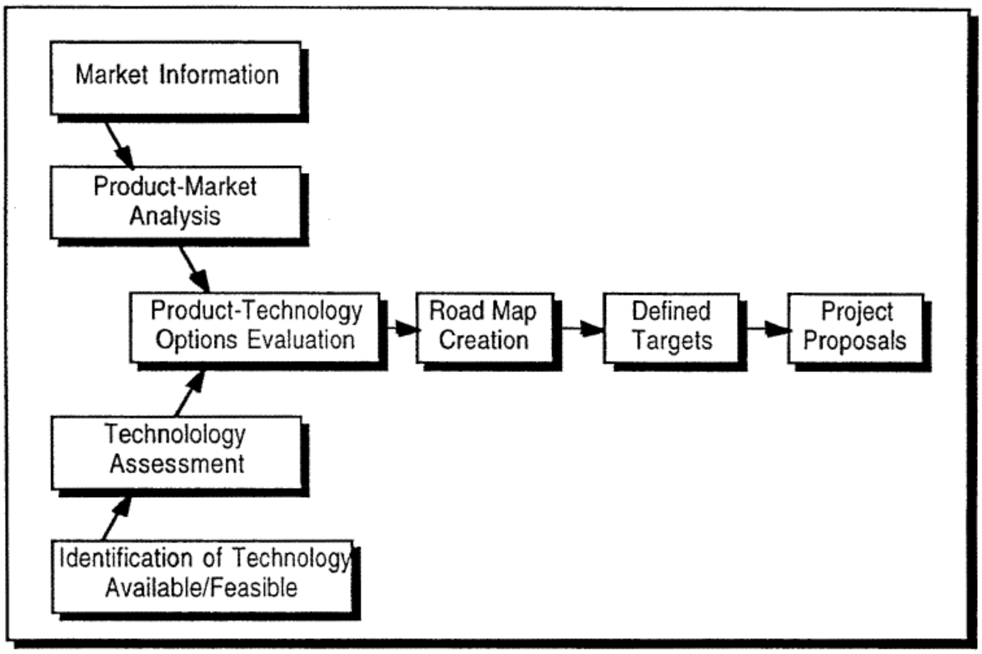


Fig. 2.2 Flowchart of strategic technology planning (Probert & Shehabuddeen, 1999)

This strategic technology planning indicates two important elements for roadmap creation, namely, market information and available/feasible technology. These elements are applied to this study in building the models for roadmap assessment. However, the relationship among the market, technology, economic status, societal challenges, resource allocation, and other environmental factors must be examined.

2.3.1.3 T-Plan model

Fig. 2.3 shows that another technology management framework highlights communications between commercial and technological functions in the business to support effective technology management (Phaal et al., 2001b). Technology management includes five main steps: identification, selection, acquisition, exploitation, and protection. This framework shows a working system for technology roadmapping, including interrelationships between commercial and technological perspectives, technology-based development, and external environment. The framework is also adopted as a fundamental support for the roadmap assessment in this study.

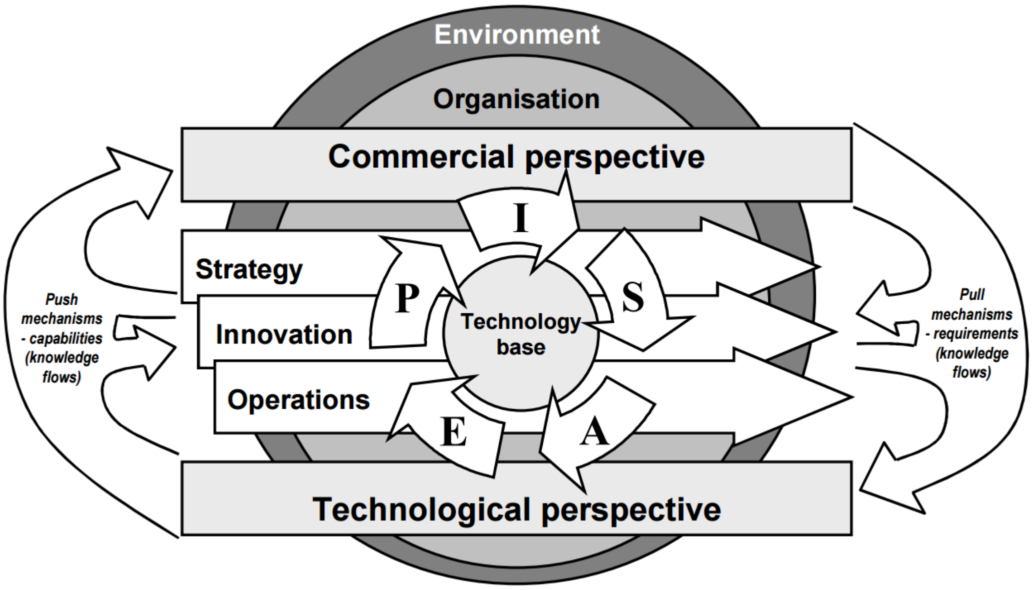


Fig. 2.3 Technology management framework (Probert et al., 2000)

Based on the actual experiences of firms in several sectors, a fast-start technology roadmapping (i.e., "T-Plan") for product planning was introduced (Phaal et al., 2001a). The T-Plan includes two main parts—the standard and customized approaches.

The standard approach is elaborated by Rip and Kemp (1998), as shown in Fig. 2.4. Following the time axis, the standard approach consists of four steps from market, product, and technology assessment to synthetic roadmapping. This flowchart is often applied to the market-pull product development.

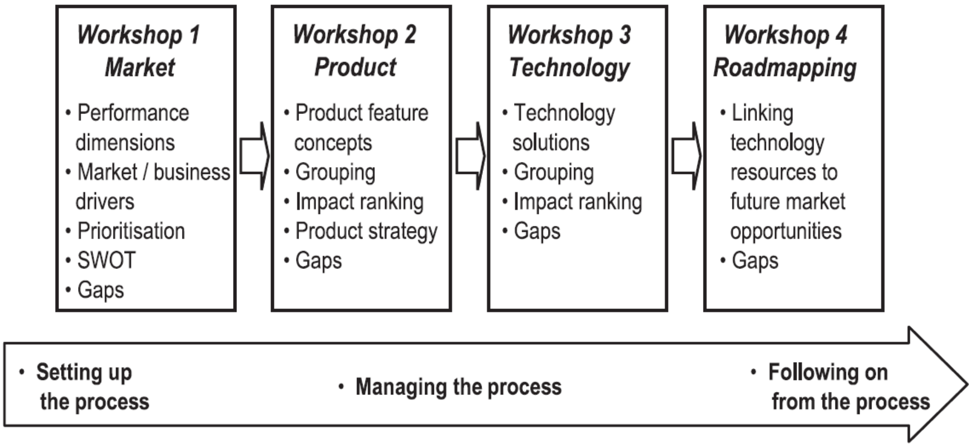


Fig. 2.4 T-Plan: Standard approach to roadmapping (Rip & Kemp, 1998)

To provide a specific roadmap for a target firm, a customized process should be conducted on the basis of general information gained in the previous standard process. The T-Plan proposes both standard and customized approaches for technology roadmapping with a list of methods and provides important guidelines for later roadmap development in different levels. However, the plan does not clarify how to organize the contents of roadmap for linking technology resources to future market opportunities in the roadmapping workshop.

2.3.1.4 Corporate-level applications of technology roadmap

Technology roadmaps have been widely used in the corporate level. According to a survey conducted in 1999, ten percent of the medium- or large-scale manufacturing companies in the UK adopted roadmapping for strategic development, and most of the roadmaps were market driven (Phaal et al., 2001a). A large number of case studies and action research on technology roadmap applications in firms have been conducted in different regions or countries. Listed below are examples.

a) Motorola's technology roadmap was recognized as the most famous case at the corporate level because it successfully attracted attention on the benefits of technology roadmaps. The entire process, from objectives, methodologies, roadmapping, and implementation, was systematically reported (Willyard, 1987).

b) Lucent Technologies, as one of the few companies who adopted technology roadmap in the early period, reported its experience on deploying roadmaps across the corporation for several years in 2003 (Albright & Kappel, 2003).

c) Groenveld (2007) created another famous corporate product-technology roadmap in Philips Electronics, introducing how he determined technical product functions in terms of customer requirements and research and development projects to build necessary techniques for product creation.

d) Robinson et al. (2006) published a knowledge management maturity roadmap (STEPS) for corporate sustainability and conducted a large-scale survey in the construction industry in the UK. An in-depth study on eight selected firms was carried out from management to implementation on the basis of STEPS.

e) Gerdsri et al. (2009) discussed the dynamics of technology roadmap implementation and reported a case study on SCG Building Materials Co., Ltd in Thailand from initiation and development to integration stages.

f) Caetano and Amaral (2011) introduced a method of technology push (MTP) for technology roadmapping and applied it to an action research in a Brazilian corporate with an integrated strategy of technology push and partnership in open innovation environments.

g) Geum et al. (2011) focused on product-service integration technology roadmapping and conducted a case study on U-Healthcare with technology as an indirect enabler in Korea.

h) A research team in Russia proposed integrated roadmaps and corporate foresight as tools of innovation management and applied these tools to a number of big Russian companies in energy and transportation sectors from 2008 to 2013 (Vishnevskiy et al., 2015).

2.3.2 Industry-level technology roadmap

Technology roadmaps have also been adopted for industrial strategic management since the early 1990s (Galvin, 1998; Nimmo, 2013). Technology roadmapping across industry sectors has been recognized as beneficial for collaboration, information exchange, network establishment, and fund usage (Laat & Mckibbin, 2003). In the following subsections, three main models of technology roadmaps for industries are introduced.

2.3.2.1 ITRS model

International Technology Roadmap for Semiconductors (ITRS) has been recognized as the earliest and most influential roadmapping model at the industrial level since the Semiconductor Industry Association (SIA) of the US published a document in 1992 (Semiconductor-Industry-Association, 1992). The idea of a technology roadmap for semiconductor industry was proposed by Moore, Chairman of the SIA Technology Committee. The first report released a roadmap for a 15-year period (from 1992 to 2007) with 11 individual technology roadmaps, which addressed leading-edge and mainstream technology for integrated circuits (Garcia, 1997). This was the embryonic form of a technology roadmap for the industry. Fig. 2.5 depicts the SIA technology roadmap workshop.

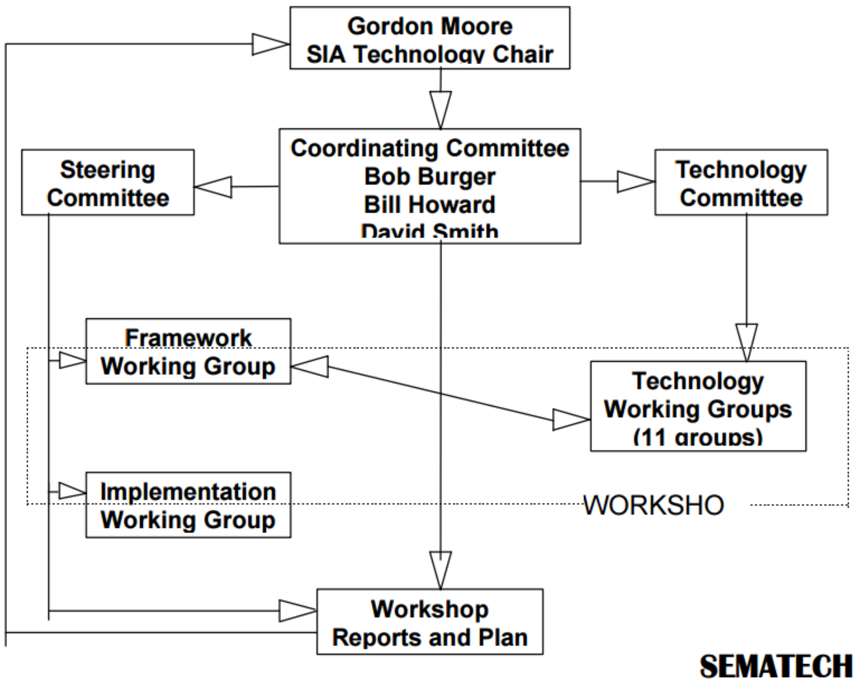


Fig. 2.5 SIA technology roadmap workshop (Garcia, 1997)

In 1998, the development of technology roadmaps for semiconductors became an internationally collaborative activity held by a group of participants, including SIA and corresponding affiliations of the US, Europe, Japan, Korea, and Taiwan, and then later established ITRS (Arden, 2002b). Based on the international semiconductor industry development, the technical scope for ITRS was drawn (see Fig. 2.6), which was the first time that a technology roadmap defined the technical scope in detail from the literature. To better apply semiconductors to different areas, technology roadmapping approach for applications, architectures, and integrated circuits were also developed, as illustrated in Fig. 2.7. According to different application areas, technology roadmaps made adapted envisions on technologies and parts. Doing so provided clear routines for technology development and future management with specific purposes.

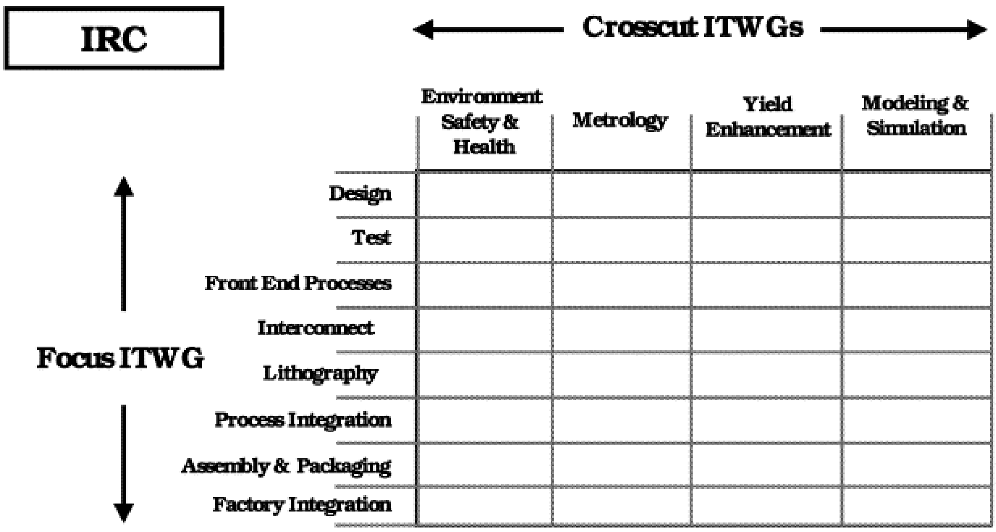


Fig. 2.6 Technical scope of the ITRS with International Technical Working Groups (ITWGs) and International Roadmap Committee (IRC) (Arden, 2002b)

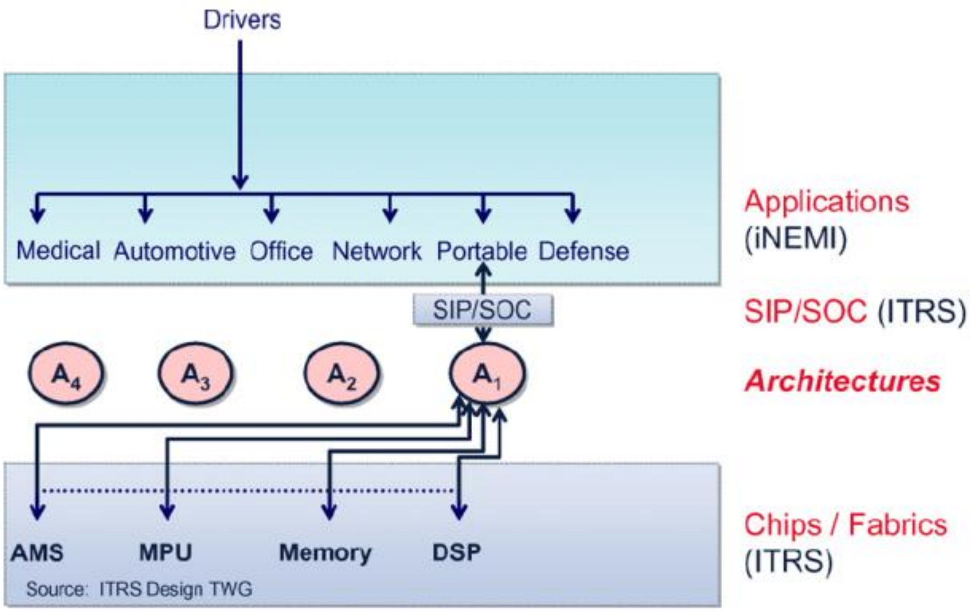
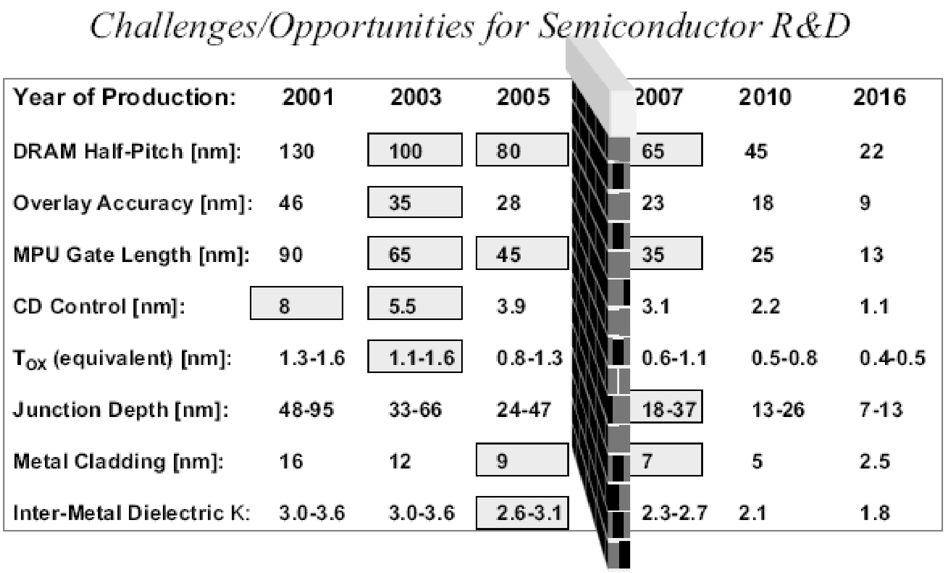


Fig. 2.7 Mapping approach (Arden, 2006)

Another feature that made ITRS different from previous technology roadmapping methods was that it predicted and visualized industrial technology barriers for semiconductor research and development. Fig. 2.8 presents a vivid sample.



Year of Production:	2001	2003	2005	2007	2010	2016
DRAM Half-Pitch [nm]:	130	100	80	65	45	22
Overlay Accuracy [nm]:	46	35	28	23	18	9
MPU Gate Length [nm]:	90	65	45	35	25	13
CD Control [nm]:	8	5.5	3.9	3.1	2.2	1.1
T_{OX} (equivalent) [nm]:	1.3-1.6	1.1-1.6	0.8-1.3	0.6-1.1	0.5-0.8	0.4-0.5
Junction Depth [nm]:	48-95	33-66	24-47	18-37	13-26	7-13
Metal Cladding [nm]:	16	12	9	7	5	2.5
Inter-Metal Dielectric K:	3.0-3.6	3.0-3.6	2.6-3.1	2.3-2.7	2.1	1.8

Fig. 2.8 "Red Brick Wall" of key challenges in future silicon technology outlined by ITRS (Arden, 2002a)

ITRS contributed greatly to the development of ITRM. However, it had a limitation, that is, resource monopoly. The organization that founded ITRS was a consortium of five affiliated associations in top-developed regions, thus maintaining high-level competitiveness in the semiconductor industry.

2.3.2.2 Korean TechStrategy model

Many scholars and their research teams in Korea started studies on technology roadmap in this decade. They published a series of research techniques for roadmapping and applications for the industry. At the early stage, (Lee et al., 2007) proposed a systematic process and detailed procedures to build an ITRM with an application to Korean part and material industry (Lee et al., 2007). Fig. 2.9 illustrates the overall framework of TechStrategy for R&D sector. This roadmapping technique focused mainly on how to meet operational requirements for R&D project actualization, dealing with technology needs and filling gaps. The concepts of a R&D project were first highlighted and distinguished with integrated technology roadmap for the overall industry, providing important literature support for later research. However, relationship between market and technology was missing, and technology was emphasized and isolated from market forces.

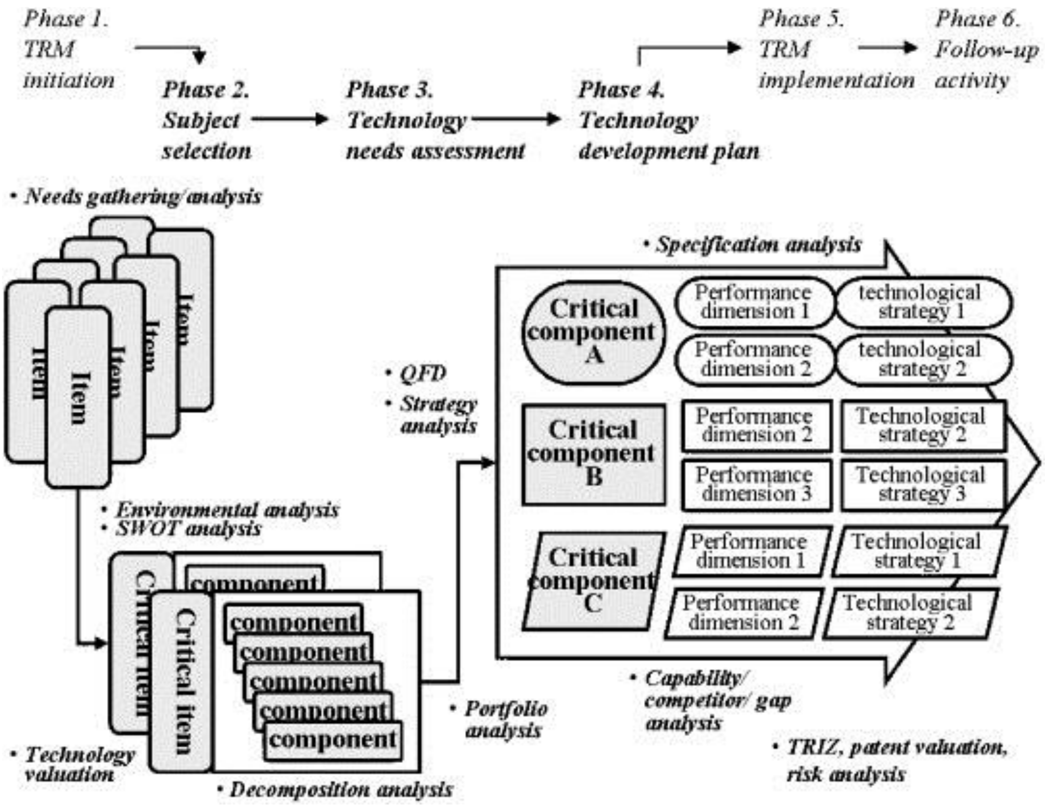


Fig. 2.9 Overall framework of TechStrategy (Lee et al., 2007)

In addition, patent analysis was recommended for technology-driven roadmapping. Despite missing specific statement of application levels (corporate or industry), it could also be applied in ITRM because patent search usually represents the status of an industry rather than a single corporate. As shown in Fig. 2.10, a technology-driven roadmapping process was proposed, linking technology through factual data of “existing and to-be-developed technology assets” (Lee et al., 2009a). Other studies also mentioned patent analysis for market-driven roadmapping (Lee et al., 2007; Lee et al., 2008; Phaal & Robert, 2013). The strength of this technique lies in collecting factual information to illustrate the technological capacity of an industry for roadmapping.

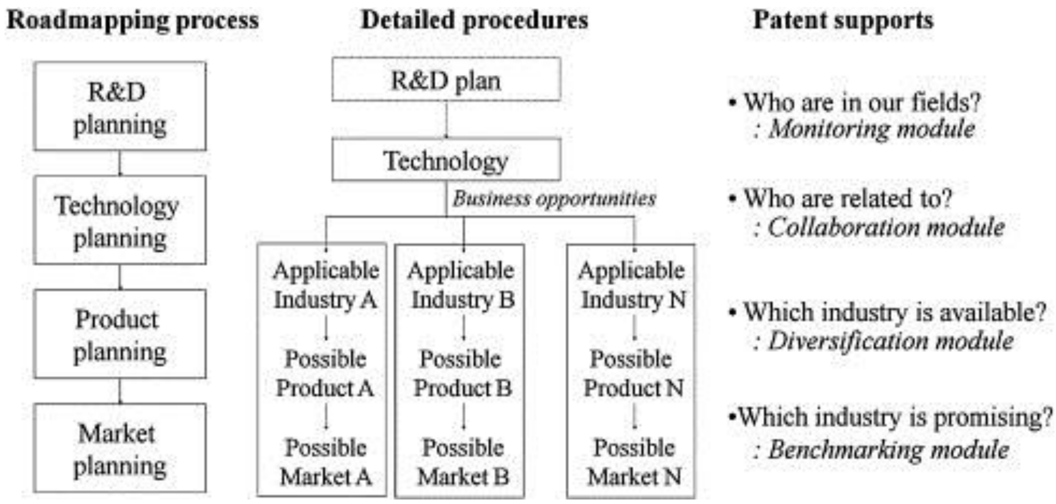


Fig. 2.10 Technology-driven roadmapping (Lee et al., 2009a)

2.3.2.3 Industrial-chain-based technology roadmap

Majority of ITRMs were developed on the basis of models created for corporate level. Presently, only a few studies focused on the development of customized models for ITRMs. Introduced from a funded project of the technology and science department of the local government in Guangdong Province in China, members of the team working on the current research have published a series of studies (Li et al., 2010; Xiong et al., 2010; Yao et al., 2010) on industrial-chain-based roadmaps for industry level.

The development of ITRM, as illustrated in Fig. 2.11, includes preliminary preparation, deployment, and finalization (Li et al., 2010c). The proposed methodology is applied in the textile and clothing industry (Hu et al., 2010a, 2010b; Li et al., 2010a; Li et al., 2010b; Li et al., 2013a; Li et al., 2012; Lv et al., 2010; Wang et al., 2010; Xiong et al., 2010; Yao et al., 2010a; Yao et al., 2010b).

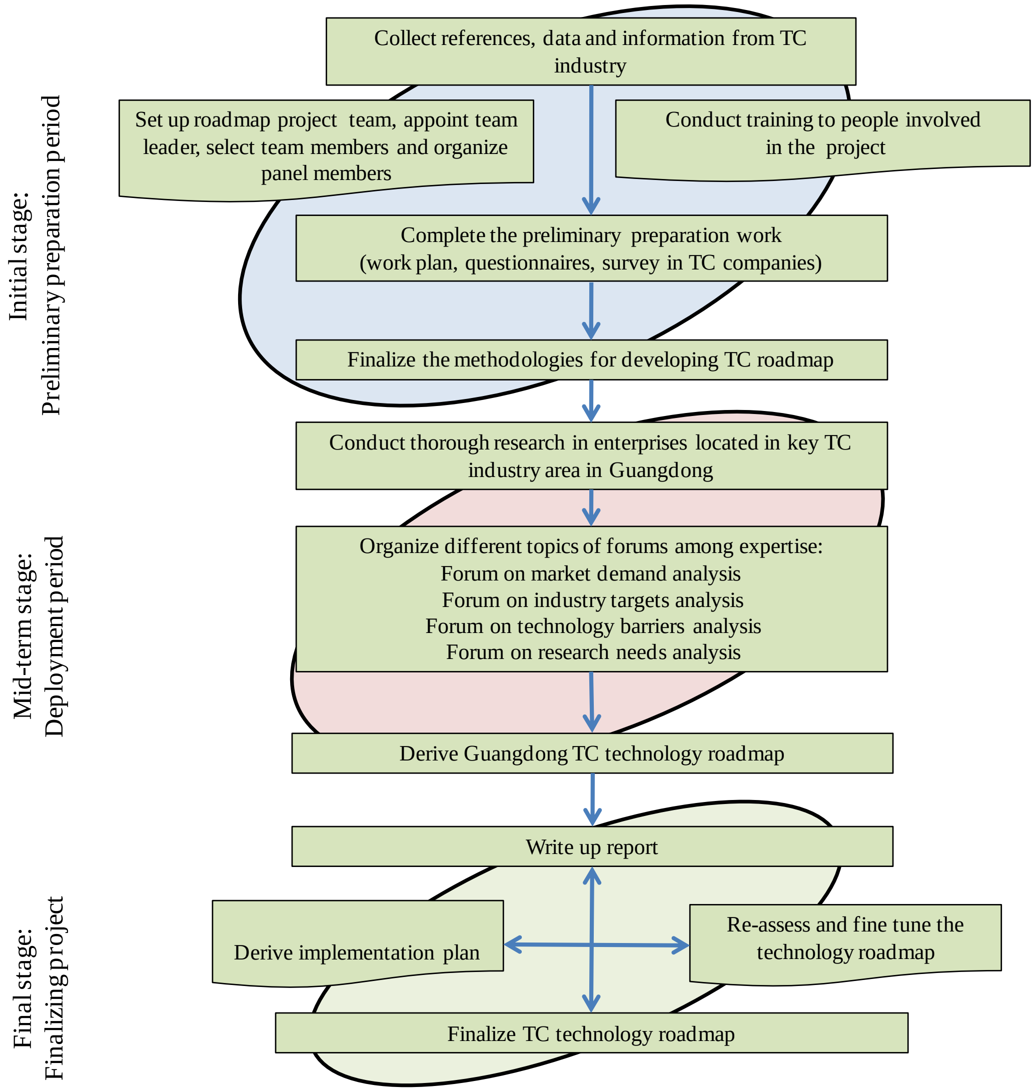


Fig. 2.11 Roadmap development process (Li et al., 2010c)

To adopt the requirements of the industry, an innovative method of technology roadmapping was created, providing the integrated blueprint of the industry with industry chains, products for different markets, and innovation sectors (Li et al., 2014). The industry chain-based model creates an innovative platform to boost the industrial communication among different sectors longitudinally and facilitate collaboration between competitors within the same sector. The recycling sector was also included in the traditional ITRM for the first time. However, logical relationships among research areas, industrial chains, and specific technologies had not been illustrated. Given the information amount of an industry, comprehensive technology roadmaps for each sector or research area could be further elaborated. This industrial-chain-based method is adopted for roadmap assessment in this study to analyze the relationships among industrial chains, industrial goals, key technology, and environmental circumstances.

2.3.2.4 Industry-level applications of technology roadmap

Corporate technology roadmaps were generally initiated by the firms, whereas ITRMs were often launched by government-funded programs or industrial planning of public organizations. Listed below are examples:

a) In 1994, the SIA of the US published the first technology roadmap (Semiconductor-Industry-Association, 1992), before establishing the consortium ITRS. Afterward, ITRS outlined research contributions from invited international experts to map the technology routine on R&D needs for a 15-year period in 2001, and the report was updated in 2003 (Allan et al., 2002; Edenfeld et al., 2004). Recently, ITRS released a second collaborative 15-year horizon roadmap to assess technical challenges and opportunities for the industry to 2028 (Rosso, 2014).

b) Jennings et al. (1998) published a roadmap of agent research and development to provide an overview of R&D and their relationships in and between and highlight future challenges in the field of autonomous agents and multi-agent systems.

c) Industry Canada, a department of the government of Canada, used technology roadmap to guide their industries for innovative products and processes to meet the market's new demands, such as technology roadmaps in the Canadian textile industry (Industry-Canada, 2008) and lumber and value-added wood products (Industry-Canada, 2005).

d) In Korea, technology roadmaps have been widely adopted over the last decade, in the part and material (Lee et al., 2007), energy, (Lee et al., 2009b) and electric industries (Lee, 2005).

e) From 2010 to 2012, a series of technology roadmaps to 2025 in various industries were developed by the Chinese Academy of Sciences, covering energy, space, marine, advanced manufacturing, information, public health, agricultural, advanced materials, ecology, and environment (Chen et al., 2010; Chen, 2010; Guo & Wu, 2010; Li, 2011; Liu, 2012; Wang, 2012; Xiang, 2010; Zhao, 2010).

2.3.3 Policy-level technology roadmap

Technology roadmap has been adopted not only in corporates and industries but also in policy management, especially for governments. In the mid-1990s, technology roadmap was adopted to provide intelligence for policy making in areas where science and technology play dominant roles (Costa et al., 2005).

Policy-level technology roadmap provides strategic intelligence that optimizes public technology and innovation inputs (Costa et al., 2005) to fulfill the expected status of a system is the key subjective, which may involve various power and resources from the population, society, political parties, and capital. In the following subsections, two main models that contributed greatly to the development of technology roadmaps for policy, as well as representative applications and practices, are presented.

2.3.3.1 European electronic-government model

To identify and envision important research challenges, technology roadmap to 2020 has been applied as the characteristic-matched methodology for governments in Europe. Scholars stated that policy technology roadmaps needed in-depth considerations of technological developments, corresponding industries, broad sociocultural and socioeconomic trends, and demand and practitioner needs (Wimmer et al., 2008).

As shown in Fig. 2.12, a comprehensive technology roadmapping methodology had been proposed for e-government by the partners of the consortium. Workshops and online consultations were the main instruments been used in this model. A sample roadmap of 13 themes for trust in e-government is illustrated in Fig. 2.13.

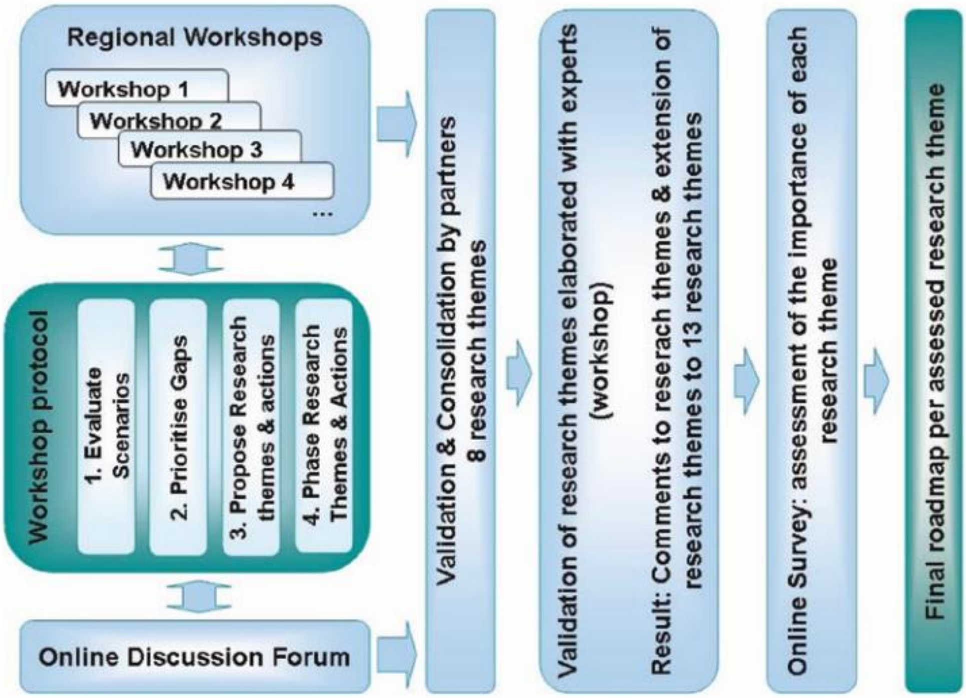


Fig. 2.12 Overall eGovRTD2020 technology roadmapping methodology (Wimmer, 2007)

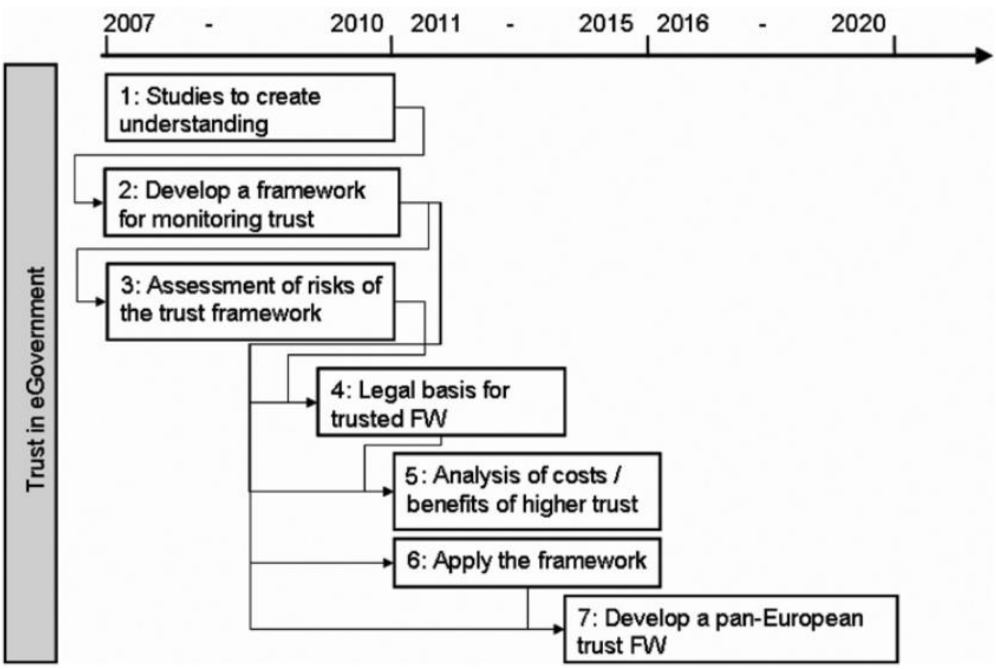


Fig. 2.13 Roadmap for trust in e-government (Wimmer et al., 2007)

The overall methodology in Fig. 2.12 shows the organization of workshops, expert forums, and surveys. The methodology provides guidelines for the later development of expert panels for roadmapping. The roadmap for trust in e-government illustrates an example of the policy-making roadmap, but each task needs further elaboration.

2.3.3.2 Japanese governmental model of innovation policy

After the economic downturn in the 1990s, the Ministry of Economy, Trade, and Industry of Japan (METI) started to do long-term R&D planning in 2000. To improve the public understanding of potential markets, technology priority, and METI's invested projects and facilitate cross-sector alliances for interdisciplinary technology convergences, METI published technology roadmaps in governmental innovation policy. METI created its own characteristic structure in roadmapping of three layers (see Fig. 2.14).

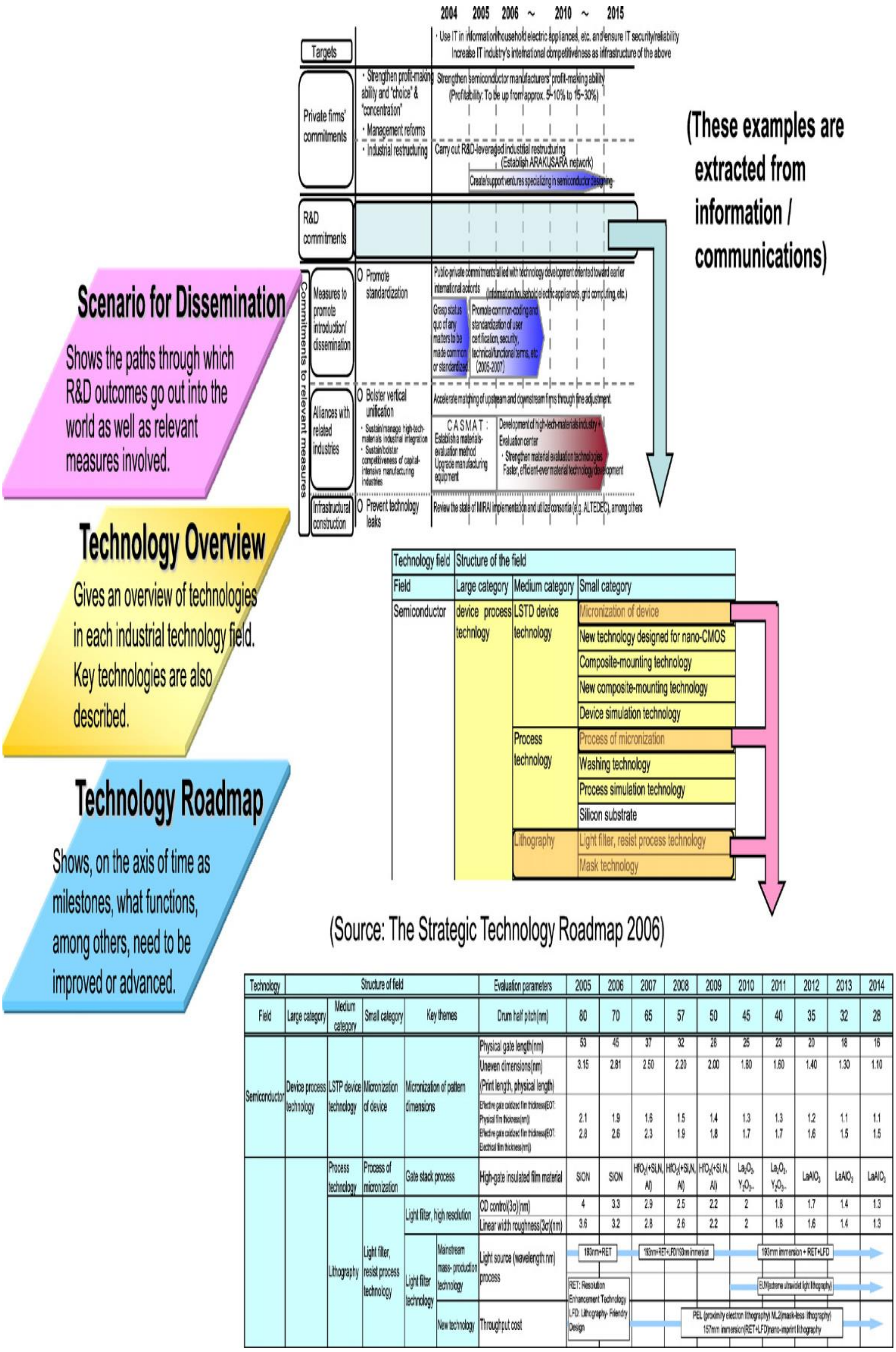


Fig. 2.14 Structure of METI's strategic technology roadmap (three-layer structure)

(Yasunaga et al., 2009)

The first layer on the top shows the dissemination scenarios to connect R&D and other involved policy. The second layer represents the technology mapping to identify prioritized technologies, and the third layer is the technology roadmap to specify the time axis and development levels. This unique model tailors technology roadmapping technique to adopt the characteristics of governmental policy management and information sharing, which contribute fundamental literature support to the policy-oriented roadmapping (Yasunaga et al., 2009).

In addition, METI defined three different types of methodologies. For example, the electronic area was developed by market-pull power and they would be evaluated by top-down means from the market forecast and product roadmap to technology roadmap (Yasunaga et al., 2009). The detailed information is illustrated in Fig. 2.15. The social-needs-driven roadmaps were first proposed, which would help the government to make strategic intelligence decisions in specific flows based on the characteristics of the planned areas.

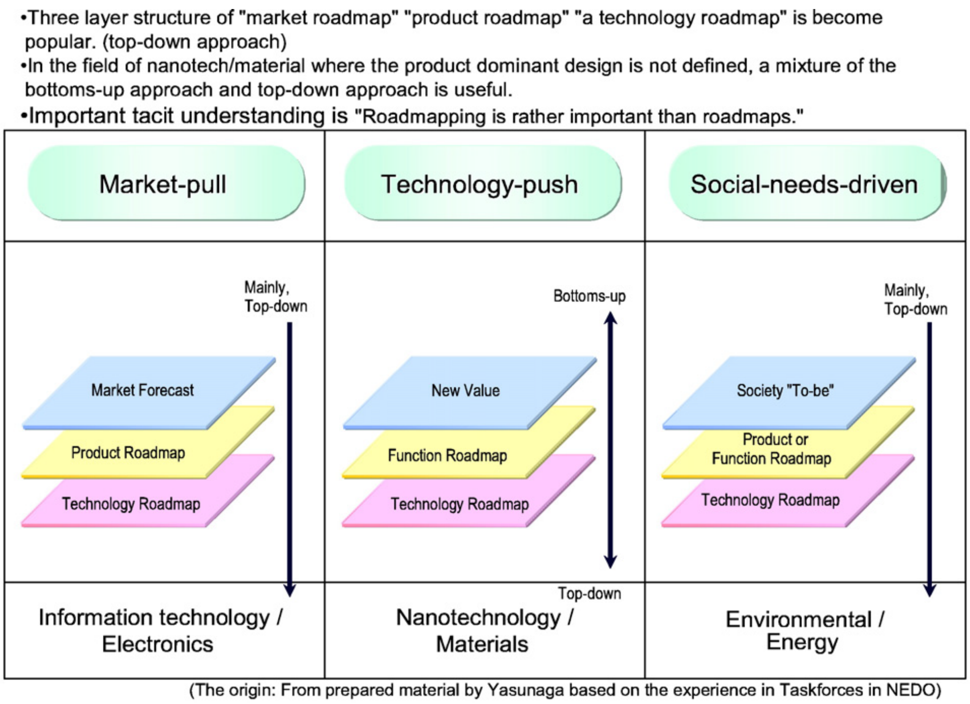


Fig. 2.15 Three types of roadmapping methodologies (Yasunaga et al., 2009)

2.3.3.3 Policy applications of technology roadmap

Technology roadmaps have been adopted to provide intelligence for policy making for more than two decades (Costa et al., 2005). The European Union (EU) has become the most active user of technology roadmaps for organizing resources in different nations to achieve better visions of united development. Using technology roadmapping, EU identified a large number of research themes, including trust in e-government, semantic and cultural interoperability of public services, information quality, assessed value of government ICT investments, participation, citizen engagement and democratic processes, mission-oriented goals, and performance management (Wimmer et al., 2008).

The Ministry of Economy, Trade and Industry of Japan developed more than 20 technology roadmaps, such as semiconductors, storage and solid-state memories, computers, networks, medicine, cancer cures, CO_2 fixation and utilization, countermeasures to chlorofluorocarbon emissions that damage the ozone layer, chemical product management and countermeasures for toxic chemicals, reduce, reuse, and recycle, and energy (Yasunaga et al., 2009).

Costa et al. (2005) examined science and technology roadmapping for policy intelligence from scope, objectives, and processes to implementation, in which they introduced technology roadmap applications in healthcare and information and communication technologies.

Daim and Oliver (2008) implemented technology roadmap for a government agency in energy service sector and created a set of roadmapping processes for energy service policy making.

2.4 Industry technology roadmap for textiles

The UK government funded research projects to identify and address the sustainability impacts of the products, services, and materials consumed in the UK from 2001 (Department for Environment, Food & Rural Affairs, 2013). Defra conducted 10 technology roadmaps, including “The environmental and social impacts across the life cycle of clothing” (Madsen, 2007). To maintain its competitiveness in the global markets, the Canadian textile industry established a TRM Steering Committee with industrial and organizational representatives and Advisory Committee to create a technology roadmap to determine its future positioning, in which technical textile and other value-added textiles had been targeted (Industry-Canada, 2008). In China, cooperative project “Industry technology roadmap for textile and clothing industry in Guangdong Province” was conducted by a joint group of experts from academia, industry, and government, in which roadmaps in 10 areas were developed (Li & Xiong, 2010b). Kim (2009a) developed an ITRM for the flushable pre-moistened nonwoven wipes industry, as an academic thesis, to provide an in-depth study on governmental investments on research, development, and manufacturing.

2.5 Assessment of technology roadmaps

One of the issues left unaddressed in the literature is the lack of assessment methods for technology roadmaps (Carvalho et al., 2013; Vatananan & Gerdsri, 2012). A small but growing body of literature has assessed the success of roadmaps for companies and industries.

Phaal et al. (2001) proposed fast-start technology roadmapping and applied it to 10 selected companies. To assess the effectiveness of each case and make improvements to the processes, Phaal et al. assessed the usefulness, functionality, and usability of the roadmap through the ratings of company users. Ten success factors and corresponding barriers were then identified (Farrukh et al., 2003; Phaal et al., 2001b). Fig. 2.16 illustrates the results summarized by Jeffrey et al. (2013).

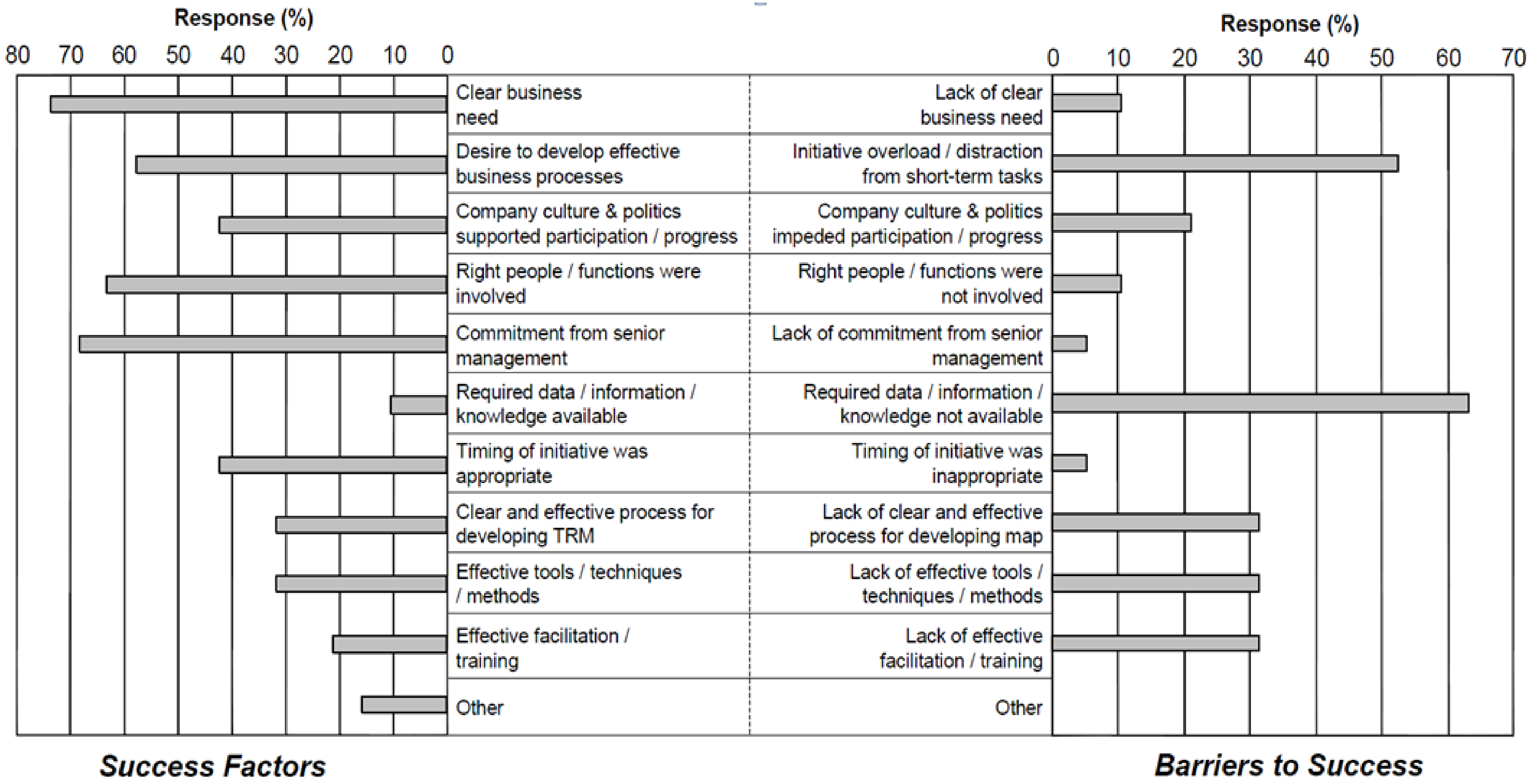


Fig. 2.16 Roadmapping success factors and barriers to success (Jeffrey et al., 2013)

The top five success factors include (1) stating clear business need, (2) getting commitment from senior management, (3) involving right people or functions, (4) desiring to develop effective business processes, and (5) company culture and politics supporting participation or progress and timing of initiative being appropriate. The most concerned barriers to success are lacking required data, information, or knowledge and initiative overload or distraction from short-term tasks.

This study is commonly regarded as the first formal assessment of the success of roadmaps. The main limitation, however, is the yet-developed theoretical foundation or application scopes.

Gerdsri et al. (2009) proposed the stage of technology roadmap implementation and indicated measures for the success of a corporate-level roadmap in different stages. For the initiation stage, acceptance by key stakeholders and development of customized process were listed. The quality of content presented in a roadmap and knowledge sharing among different groups of participants were selected as key measures in the development stage, followed by the integration stage of linkage between a roadmap and corporate strategic plan and continuation of the TRM (technology roadmap) implementation. The details are presented in Fig. 2.17. Gerdsri et al. also concluded that the "critical components to the success of TRM implementation are people, processes and data" (Gerdsri, 2007b), and right people and resources aligned with the process should be well planned (Gerdsri & Assakul, 2007). However, specific assessment methods of those measures have not been discussed further.

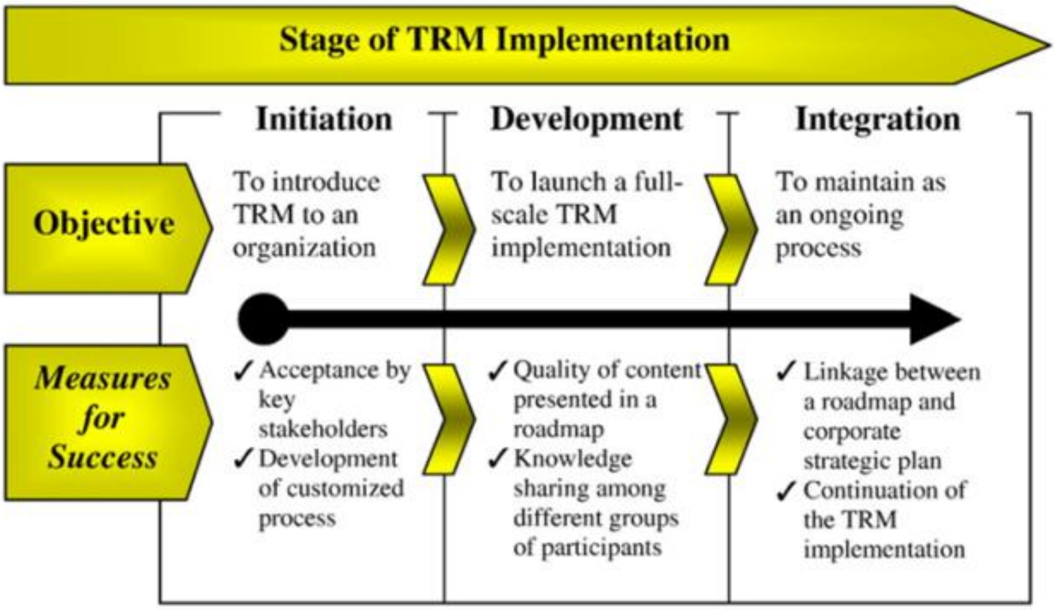


Fig. 2.17 Objective and measures for success in stages of TRM implementation (Gerdsri et al., 2009)

Success factors were also mentioned in the work of policy-oriented technology roadmapping. (Costa et al., 2005) identified five success factors, namely, prioritization, inclusion of human factors, transparency, reliability, and user-friendliness of the outputs.

Lee et al. (2012) conducted a research to elaborate a theoretical foundation to identify core factors for a roadmap and how these factors affect the technology roadmap's credibility judged by roadmap users. Based on Berlo's communication model of Source, Message, Channel, and Receiver, Lee et al. (2012) proposed five hypotheses, as shown in Fig. 2.18.

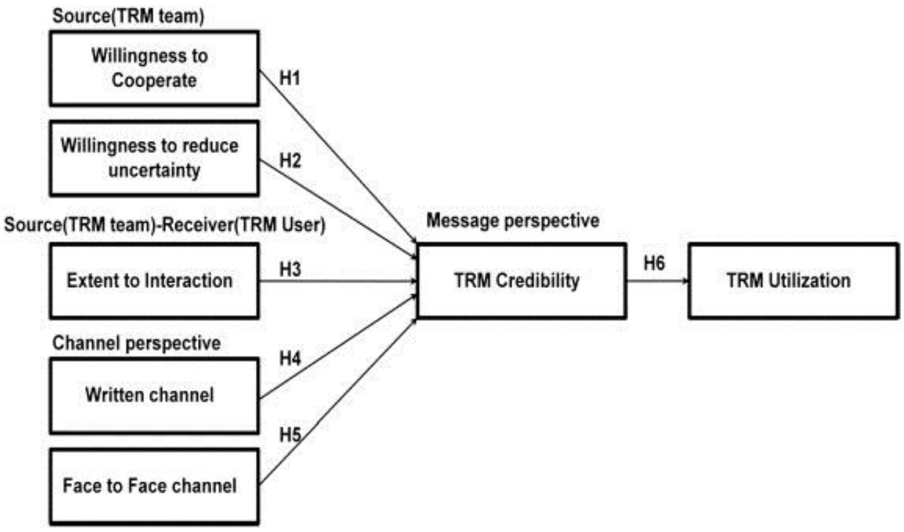


Fig. 2.18 Proposed hypotheses (Lee et al., 2012)

The results showed that higher perceived technology roadmap credibility resulted in higher level of roadmap utilization, and the credibility would be higher if the roadmapping members' willingness to reduce uncertainty was higher (Lee et al., 2012). This was a pilot study on technology roadmapping assessment and classic communication method and provided useful guidelines for future communication skills in the technology roadmap project. However, it mainly focused on communication attitudes and styles of the roadmapping team and the roadmap users.

Jeffery and his research team (2013) proposed the nine-metric assessment criteria for technology roadmap, as shown in Table 2.1. The first five metrics were based on the previous work on traditional success factors, and metrics six to nine aimed to evaluate the success level of a technology roadmap by assessing whether its objectives had been achieved. These metrics were developed to assess multi-organization technology roadmaps for the industry. With the assessment method proposed, four industry-level technology roadmaps in marine energy and wind energy were scored from 1 (low) to 10 (high).

Table 2.1 Nine metrics to assess the success of multi-organization TRM (Jeffrey et al., 2013)

Type	Metric	How metric is assessed
Metrics assessing the architecture of the TRM and how it was prepared.	1. Author	Scored depending on the reputation of the author and who they selected to be a part of the TRM process (this is a traditional success factor for compiling a roadmap).
	2. Target audience	Scored based on how well the roadmap addresses its entire target audience.
	3. Roadmap message, effectiveness of delivery	Analyses a roadmap's message and how well it is delivered, taking into account format consistency and language.
	4. Are the stakeholders adequately addressed?	Measures how well, and how evenly, the stakeholders relevant to the roadmap are addressed.
	5. Ease of use – method used	Measures how easy to follow the roadmap is for readers from a range of backgrounds.
Metrics assessing the results of the TRM and whether it has achieved its objectives.	6. Status of suggested policies	Scored based on whether the roadmap's suggested policies have been implemented or are in the process of being implemented.
	7. Citations and references	Scored based on the number of times the roadmap has been cited (highest weighting for citations by another roadmap or by government).
	8. Technology	Scored based on whether the roadmap's technology recommendations have been, or are in the process of being developed.
	9. Supply chain	Scored based on whether the roadmap's supply chain recommendations have been or are in the process of being implemented.

According to the analysis results of the four roadmaps, the research team concluded and recommended guidelines for implementing a successful roadmap: (1) having the right people/author in places, (2) targeting audience involved as a key stakeholder in the roadmap's development, (3) keeping the roadmap "alive" by regularly reviewing and updating it and using it as an open line of communication with the target audience, (4) determining an even target audience and effectively addressing them, (5) defining clear, defined goals and prioritized objectives to avoid doing too much, (6) ensuring effective layout and structure and efficient use of visual graphs and charts, (7) focusing on clarity and use of concise language, and (8) choosing a robust method for developing the roadmap (Jeffrey et al., 2013).

Both the content architectures and implementation results were assessed by the authors. This work can be considered as one of the first practices of ITRM assessment; however, theoretical support for the metrics and a scientific method for assessment were lacking. The data of actual results presented in this study were generated from subjective judgments instead of factual data derived from objective numbers.

2.6 Research gap

Technology roadmaps have been regarded as ample resources for strategic planning and communication technique by the corporates, industries and policy makers. Research on the assessment of technology roadmap is urgently needed (Carvalho et al., 2013).

According to the review in Section 2.5, the existing technology roadmaps are generally assessed in terms of the process or approach of roadmapping (Lee et al., 2012; Phaal & Muller, 2009), the stakeholder's comments (Gerdsri et al., 2009; Phaal et al., 2001b), the actual impacts on the target areas (Jeffrey et al., 2013), and the contents (Gerdsri et al., 2009; Kajikawa et al., 2008).

In conclusion, the major research gaps in the literature discussed so far include the following:

(1) Lack of theoretical foundation and systematic method for the internal content quality assessment of ITRMs

(2) Lack of theoretical foundation and systematic method for the external performance assessment of ITRMs

(3) Little work other than user satisfaction survey to assess the internal quality and the external performance of any roadmap

(4) Limited research on the relationship between internal quality and external performance

(5) Limited research on the success factors of an ITRM, especially for the textile industry

(6) Lack of practical experiences to develop or refine an ITRM in terms of assessment results

Chapter 3 Internal Assessment Model and Analysis

ITRMs have been widely used in the textile, semi-conductive, energy, and advanced materials industries (Arden, 2006; Lee et al., 2009b; Li & Xiong, 2010b; Lu, 2010). Thus far, various techniques and approaches have been used for roadmapping (Garcia, 1997; Lee et al., 2007; Phaal et al., 2001c, 2004), but roadmaps are yet to be well evaluated (Carvalho et al., 2013; Vatananan & Gerdsri, 2012). A small number of scholars assessed the success of corporate-level technology roadmaps, in most of which success was decided by the users' perception and favorability (Farrukh et al., 2003; Gerdsri et al., 2009; Lee et al., 2012). Recently, a few studies have initiated new assessment perspectives, such as roadmapping process (Gerdsri & Assakul, 2007; Phaal & Muller, 2009), roadmap achievements (Jeffrey et al., 2013) and structuring content (Gerdsri et al., 2009; Kajikawa et al., 2008).

With content quality as the focus, an assessment model is developed in this chapter. First, a theoretical framework with a set of attributes for ITRM content assessment is established. To explore the inner relationships among these attributes, a knowledge framework of ITRM content is illustrated to simulate the industrial development environment. Second, content analysis is proposed as the assessment approach with assessing procedures and measuring rubrics tailored for ITRMs. By using the results of content analysis, a measurement to quantify the deficiency, indicating incomplete and incorrect status, of an ITRM's content is developed. Finally, four global ITRMs for the textile industry are assessed with the proposed model. Relevant success factors of an effective ITRM in terms of content construction are recommended.

A theoretical framework and a model to assess the quality of an ITRM's content have been developed. The Cambridge Dictionary defines "content" as the ideas that are contained in a piece of writing (Cambridgedictionary, 2017). Our model is designed to assess the content in an ITRM, including descriptive data, analysis, inferences, suggestions, and development maps.

Three types of ITRM assessments are used: (1) methodological (process and approach), (2) externally targeted contexts (stakeholder's comments and actual impacts on external target areas), and (3) internal quality of roadmaps (content). In this study, ITRM assessment is focused on the internal content quality only. The internal assessment model for the ITRM is based on a theoretical framework comprising 12 key attributes that cover internal legitimacy and a knowledge framework of the roadmap content.

3.1 Theoretical Framework

Technology roadmapping is a relatively flexible tool that facilitates strategic planning for corporates, industries, and even governmental sectors (Phaal et al., 2004). Roadmapping architectures, processes, and approaches have been widely studied (Garcia & Bray, 1997; Gerdsri, 2007a; Lee & Park, 2005; Phaal et al., 2001b; Phaal et al., 2001c, 2004). However, only a few studies focused on content construction (Gerdsri et al., 2009; Phaal et al., 2001c), and this problem leads to the lacking assessments of the quality of internal content (Kajikawa et al., 2008).

Table 3.1 summarizes the key attributes relating to internal content proposed in the existing literature surrounding technology roadmaps at corporate and industrial levels. To standardize the names relevant to the textile industry, a more accurate name is selected for each attribute shown in Figure 3.1 and 3.2. Definitions of these attributes are discussed in this section.

Table 3.1 Summary of attributes mentioned in previous research

	Key Attribute	**References**	**Terms in Fig. 3.1 & 3.2**
1	Roadmapping Methods	(Gerdsri, 2007a; Gerdsri et al., 2009; Kajikawa et al., 2008)	Roadmapping Methods
2	Expert Panels	(Gerdsri, 2007a; Gerdsri et al., 2009; Kostoff et al., 2004)	Expert Panels
3	Operation/Research Team	(Gerdsri et al., 2009; Jeffrey et al., 2013; Kostoff et al., 2004)	Research Team
4	Value Creation & Activity	(Phaal et al., 2011; Zeng et al., 2014)	Value Chain
5	Demand & Supply	(Li & Xiong, 2010a; Phaal et al., 2011; Vatananan & Gerdsri, 2012)	Supply Chain
6	Science & Application	(Kajikawa et al., 2008; Phaal et al., 2011; Vatananan & Gerdsri, 2012; Yasunaga et al., 2009)	Innovation Chain
7	Targets or Objectives	(Lee & Park, 2005; Li & Xiong, 2010a; Phaal et al., 2001b; Phaal et al., 2005; Phaal et al., 2011; Zeng et al., 2014)	Industrial Goals
8	Key Technology or R&D Projects to develop	(Kajikawa et al., 2008; Kim, 2009b; Li & Xiong, 2010a; Pataki et al., 2011; Phaal et al., 2011; Zeng et al., 2014)	Key Technologies
9	Social, Economic, Political, Ecological,	(Industry-Canada, 2008; Kajikawa et al., 2008; Li & Xiong, 2010a; Madsen, 2007;	Macro Environment

	Resources, Culture, Lifestyle, Demographical	Pataki et al., 2011; Phaal et al., 2011)	
10	Infrastructure Investment, Regulation, Policy, Education, Training	(Kajikawa et al., 2008; Li & Xiong, 2010a; Madsen, 2007; Pataki et al., 2011; Phaal et al., 2011)	Micro Environment
11	Market Pull	(Groenveld, 1997; Phaal et al., 2003; Probert et al., 2003; Walsh et al., 2005; Yoon et al., 2008)	Market Forces
12	Technological Push	(Caetano & Amaral, 2011; Herstatt & Lettl, 2004; Kostoff & Schaller, 2001; Phaal et al., 2004; Yoon et al., 2008)	Technology Forces

Given that only a few publications indicated the key attributes of the content construction of ITRM, a theoretical framework is necessary so that the understanding of relations among different attributes of an ITRM can be reflected. Based on the renamed key attributes listed in Table 3.1, a theoretical framework for assessing ITRM internal content has been established (Fig. 3.1). The assessment covers internal legitimacy and a knowledge framework of the roadmap content.

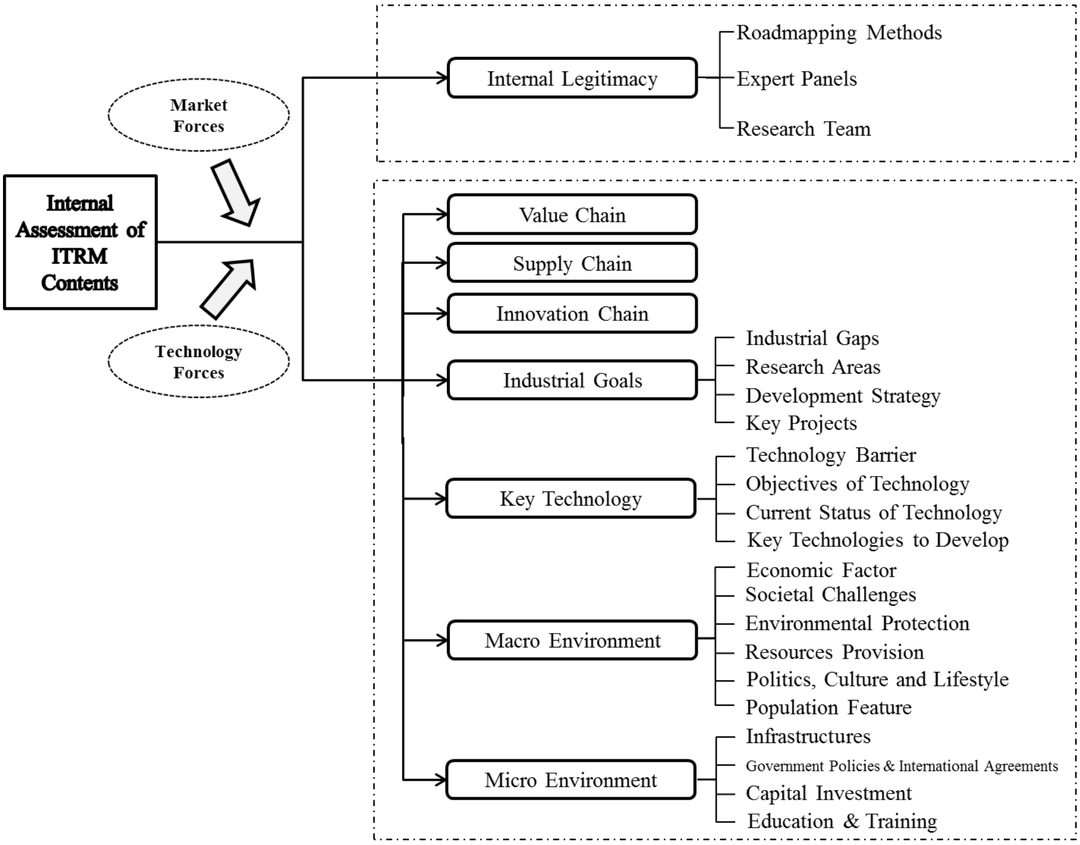


Fig. 3.1 Theoretical framework for internal assessment of ITRM

3.1.1 Internal legitimacy

Internal legitimacy analysis refers to an examination of whether the actions involved are appropriate and whether they meet the demands of the social system of norms, values, beliefs, and definitions (Suchman, 1995). The first three attributes in Table 3.1 (roadmapping methods, expert panels, and research team) are categorized as the internal legitimacy in this assessment model. Roadmapping methods can evaluate the credibility of the roadmapping design and process. Expert panels can affect the precision and timeliness of market and innovation forecasting. The research team may affect the credibility of data collection and roadmap writing.

3.1.2 Knowledge framework of roadmap content

A successful ITRM can provide sufficient and valuable content that help targeted groups of stakeholders to capture the general industrial landscapes, opportunities, and threats and to utilize the market and technological forces for achieving their objectives of future development.

The 12 attributes in Table 3.1 are integrated into a knowledge framework of an ITRM internal assessment model (see Fig. 3.2). The model simulates the mechanism for linking the content of an industry technology roadmap within the context of industrial development. The development of an industry involves a complicated interaction between the value chain (Attribute 4) and the supply chain (Attribute 5) driven by the market force; and between the supply chain (Attribute 5) and the innovation chain (Attribute 6) driven by the technology force. The industrial goals (Attribute 7) inform the value chain to affect the innovation chain. The key technologies (Attribute 8) inform the innovation chain to affect the value chain. The industrial goals are influenced by the macro environment (Attribute 9), whereas the key technology is influenced by the micro environment (Attribute 10).

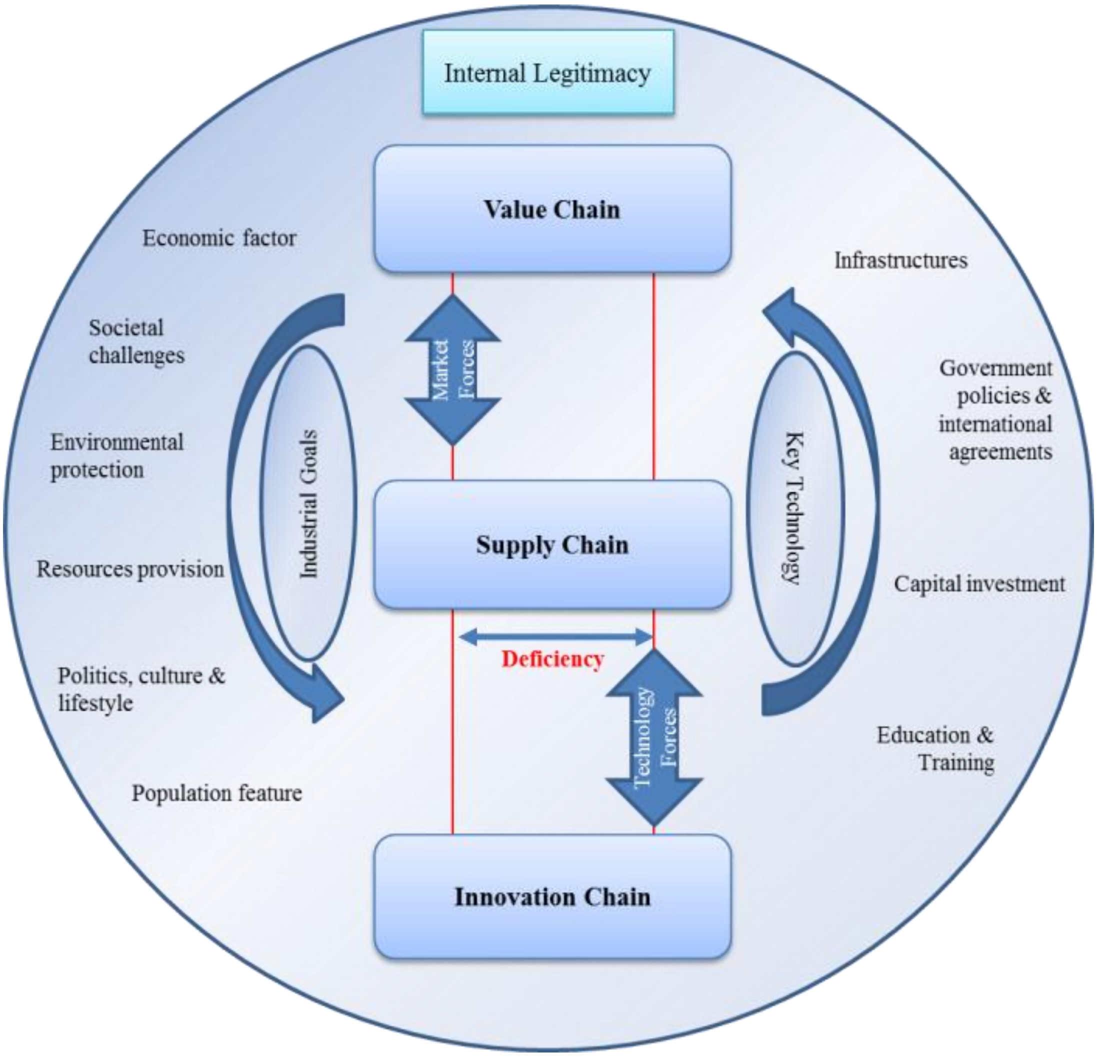


Fig. 3.2 Knowledge framework of ITRM internal assessment model

- Market and technology forces

For the industry roadmaps, the market and technology forces are complicated and involved in larger contexts. Market forces mean "the aggregate influence of the buyers and sellers on prices and quantities of goods and services offered in a market" (Mwachofi & Al-Assaf, 2011). Technology forces are the influences of technology developments on the customers, business, and society (Businessdictionary, 2017). Phaal et al. (2004) stated that the technology force links market and technology.

From an industrial perspective, the interaction among the value chain, supply chain, innovation chain, industrial goals, key technology, macro environment, and micro environment is a process to strike a balance between the market and technology forces. An imbalance exists between market and technology forces. The more well-matched market and technology forces are, the smaller the deficiency is and the better the industry develops.

A successful ITRM should provide effective information, predictions, and plans from the perspectives of both market and technology to minimize the deficiency between the market forces and technology forces within the target industry. Therefore, the eight attributes (Fig. 3.1) are categorized into two groups as detailed below.

- Market forces: value chain (price and benefit influence), supply chain (influence of goods and service offering), macro environment (influence of buying power and consuming behavior), and micro environment (influence of productivity and sales behavior)

- Technology forces: internal legitimacy (industrial influence of ITRM methodology and participants), supply chain (influence of technology for production), innovation chain (influence of technology status), industrial goals (influence of the strategies of technology development), and key technologies to develop (influence of the objectives of technology to develop)

The internal deficiency between these two groups' content quality is a key index to assess an ITRM's quality. To date, the concept of internal deficiency has originally been established for roadmap assessment. The detailed measurement is presented in Section 3.2.2.

- Value, supply, and innovation chains

ITRM covers the general landscapes of the target industry with a complete set of value, supply, and innovation chains at industrial levels that are not limited to one firm, not only upstream supply or downstream demand, and not only main technologies adopted or internal activities (Phaal et al., 2011; Zeng et al., 2014). However, the examples have yet to be fully illustrated in the literature.

Porter (2008) claimed that the value chain has primary activities and support activities. Primary activities involve inbound logistics for adding value by processing the product, outbound distribution to the points of sale, marketing, and sales to brand it and promote it as well as post sales service. The support functions include the infrastructure, management systems, human resources, procurement in the required speed, accuracy, and quality. All these multi-linked functions are in the value system (Kaplinsky & Morris, 2001; Nabyla, 2015). The value chain involves the value creation and competitions among participants within the same segment (Horvath, 2001; Porter & Millar, 1985). Maximum value creation is a common objective for all business units in an industry and thus an essential attribute in the ITRM.

Supply chain refers to the supply and demand of goods and services across various segments in the longitudinal relationship between the upstream suppliers and downstream buyers. Previous studies (Kajikawa et al., 2008; Li & Xiong, 2010a) have defined the generic framework of the content of the supply chain for ITRM as in Fig. 3.3.

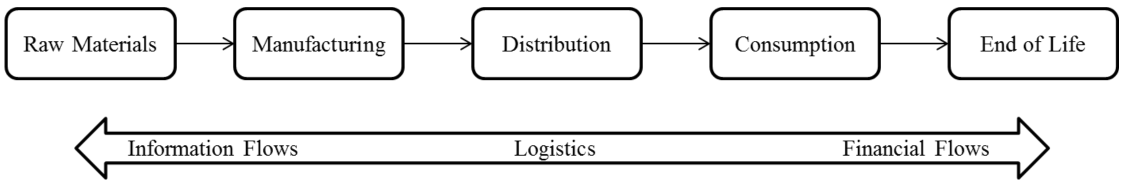


Fig. 3.3 Framework of industrial supply chain for ITRM content based on (Kajikawa et al., 2008; Li & Xiong, 2010a)

Innovation chain involves a process (Fig. 3.4) from the new knowledge of science to technological invention, industrial application, and commercialization; the process may affect the customer behavior and the market (Ford & Ryan, 1981). Following previous studies on various technology roadmaps (Kajikawa et al., 2008; Vatananan & Gerdsri, 2012; Yasunaga et al., 2009), the innovation chain is also included in this study as a technology-driven attribute in the ITRM assessment model.

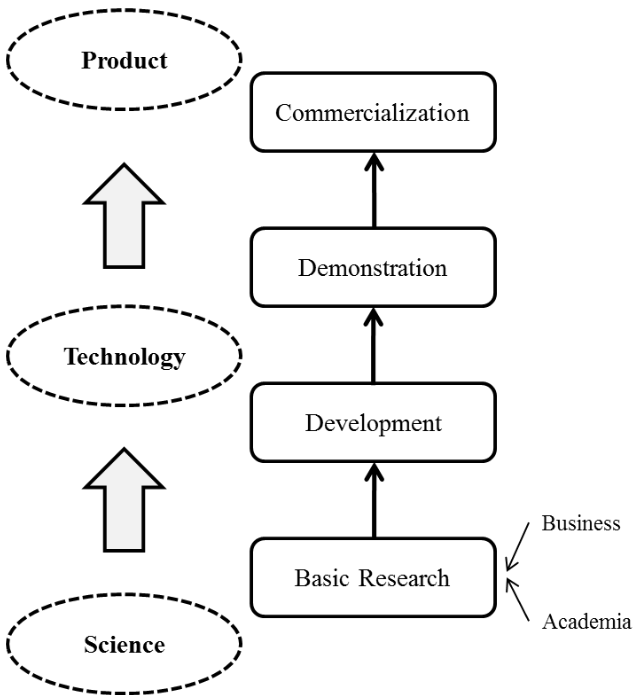


Fig. 3.4 General process of industrial innovation chain based on (Kajikawa et al., 2008; Vatananan & Gerdsri, 2012; Yasunaga et al., 2009)

The value, supply, and innovation chains are interrelated. For example, when an innovation occurs, the new products are developed and supplied at a small scale. Owing to high demand and low supply, the price increases. Then, the higher-value product will attract competing producers with greater supply. The demand will then become stable, thereby lowering the price. Finally, the market will become mature.

- Industrial goals and key technology

As mentioned at the beginning of Section 3.1.2, the industrial goals inform the value chain and the key technologies inform the innovation chain. Specific industrial goals are set to provide the products that the market treasures, as well as develop technologies for the future need (Kostoff & Schaller, 2001; Phaal et al., 2001b). The industrial goals determine the focus and direction of the industry development. To realize industrial goals, key technologies are developed to improve production effectiveness or create potential new products. If the key technologies match with the industrial goals, then the roadmap can provide effective routes to balance the market and technological forces.

- Macro and micro environment

The industrial goals are affected by the macro environment, whereas the key technology is influenced by the micro environment. Roadmaps are contextual. Content in the roadmaps cannot be isolated from multi-interacting social contexts (Pataki et al., 2011; Phaal et al., 2005). With the concepts of contextual analysis as basis (Kotler & Keller, 2006), the macro and micro environment are important to describe the contextual content of an ITRM (Pataki et al., 2011). By combining the attributes in Porter's Five Forces Model (Porter, 2008), the PESTLE Analysis (Professionalacademy, 2017), and related studies on roadmaps (Pataki et al., 2011; Phaal et al., 2011), six attributes, namely, (1) economic factors, (2) societal challenges, (3) environmental protection, (4) resources provision, (5) political, cultural and lifestyle, and (6) population features, are considered as the macro environment. Four attributes, namely, (7) infrastructures, (8) governmental policies and international agreements, (9) capital investment, and (10) education and training, are considered the micro environment in the knowledge framework of ITRM internal assessment model (Fig. 3.2).

3.2 Assessment Procedures

In the previous studies (Farrukh et al., 2003; Phaal et al., 2001b; Jeffrey et al., 2013), the content quality was only assessed by stakeholders or academic researchers subjectively. In this research, a scientific instrument of content analysis and rubrics has been developed to quantify the content quality.

3.2.1 Content analysis

Content analysis is a methodological measurement that is applied to texts (or other meaningful matter) with respect to the contexts of their use (Krippendorff, 2004; Roberts, 1997). Content analysis has been considered a reliable methodology (Lissack, 1998; Woodrum, 1984) and has been widely adopted in management research (Duriau et al., 2007; Erdener & Dunn, 1990). This method is applicable to both qualitative and quantitative data as well as inductive and deductive analysis (Elo & Kyngäs, 2008). Although the processes are purpose oriented and relatively flexible (Duriau et al., 2007; Krippendorff, 2004), the common feature of the content analysis are that the words of the text (or the information of other visual forms) are divided into categories (Burnard, 1996; Weber, 1990). Content analysis generally includes the following steps: (1) propose research question, (2) select the unit of analysis, (3) select coding/categorization scheme, (4) perform measurement, (5) check reliability, and (6) report results (Downe Wamboldt, 1992; Elo & Kyngäs, 2008; Krippendorff, 2004; Neuendorf, 2016).

Following the steps of content analysis, four experts who hold doctorate degrees and have published studies in roadmapping are invited to assess the content of an ITRM. These experts are from academic, industrial, or governmental departments.

The content is coded based on the 24 sub-attributes (see Fig.3.1), namely, (1) roadmapping methods, (2) expert panel, (3) research team, (4) value chain, (5) supply chain, (6) innovation chain, (7) industrial gaps, (8) research areas, (9) development strategy, (10) key projects, (11) technology barrier, (12) objectives of technology, (13) current status of technology, (14) key technologies to develop, (15) economics factor, (16) societal challenges, (17) environmental protection, (18) resources provision, (19) politics, cultures and lifestyles, (20) population feature, (21) infrastructures, (22) government policies and international agreements, (23) capital investment and (24) education and training. The quality of the coded content is rated by using a 5-point Likert scale (1 means a lack of relevant information, 3 means relevant information presented, and 5 means relevant information fully presented with critical analysis and solid references).

3.2.2 Quality measurement

There is no publication to quantify the overall quality of a roadmap so far. Based on the recognized definitions by Amer and Daim, the core task for a technology roadmap is to match the market demands with the technology advancement (2010), an original method has been developed to quantify whether this objective is achieved for an ITRM.

The quality of the content of different roadmaps can be presented in terms of the overall quality score (Q_o) and internal deficiency index (D_I).

First, the experts' scores are transferred into ranks. The scores for ITRMs are collected from the invited experts by content analysis, which is usually in a small sample size and distribution free. Therefore, the nonparametric test should be chosen (Frost, 2015). Given that the difference between adjacent scores for each expert may not necessarily be the same, the ranks used to perform a nonparametric test are adopted in this research (Sullivan, 2017).

The method of assigning ranks is to order the data of the same investigation group from smallest to largest. The lowest score is assigned a rank of 1, the next lowest one a rank of 2, and the largest score is assigned a rank of the total number of scores. For each sub-attribute in content analysis, the largest score is 16 (4 experts rated each of the four ITRMs, and the total number of scores is 16). When ties exist for the same sub-attribute, the average rank of the ties is assigned to each (Frost, 2015; Sullivan, 2017). Using this method, scores of each sub-attribute for all the four ITRMs rated by different experts are assigned by ranking, thereby making their comparisons meaningful.

3.2.2.1 Quality scores

After assigning ranks, the average of each key attribute's quality score (Q_i) is calculated for the ranks of different sub-attributes (Equation 1).

$$Q_i = \sum x_n \,/\, m, \tag{1}$$

where Q_i is the quality score of the *i*th key attribute (listed in Fig.1), x_n is the rank of each sub-attribute for the *i*th key attribute, and *m* is the total number of corresponding sub-attributes for the *i*th key attribute.

Given the results of Q_i, the quality scores of market-force-related attributes, technology-force-related attributes, and the overall quality score are calculated respectively by Equations 2, 3, and 4.

$$Q_{MF} = (Q_2 + Q_3 + Q_7 + Q_8)\,/4, \tag{2}$$

where Q_{MF} is the quality score of market-force-related attributes, Q_2 is the quality score of the value chain, Q_3 is the quality score of the supply chain, Q_7 is the quality score of macro environment analysis, and Q_8 is the quality score of micro environment analysis.

$$Q_{TF} = (Q_1 + Q_3 + Q_4 + Q_5 + Q_6)\,/5, \tag{3}$$

where Q_{TF} is the quality score of technology-force-related attributes, Q_1 is the quality score of internal legitimacy, Q_3 is the quality score of the supply chain,

Q_4 is the quality score of innovation chain, Q_5 is the quality score of industrial goals, and Q_8 is the quality score of key technology.

$$Q_O = \sum Q_i /8, \tag{4}$$

where Q_O is the overall quality score of an ITRM, and Q_i is the quality score of each key attribute.

3.2.2.2 Internal deficiency index

To compare the quality of the content of the market and technology forces, internal deficiency (D_I) is calculated by the absolute value of the difference between their quality scores in Equation 5.

$$D_I = | Q_{MF} - Q_{TF} | \tag{5}$$

To assess the deficiency to the quality scores relative to the average, a relative internal deficiency (R_{DI}) is also calculated (Equation 6).

$$R_{DI} = D_I \;/\; [(Q_{MF} + Q_{TF})/2] \;\; *100\% \tag{6}$$

3.3 Assessment of four ITRMs

The developed theoretical framework (Fig. 3.1) and knowledge framework (Fig. 3.2) are used to assess the internal quality of the content of four textile ITRMs at an industrial level, as shown in Table 3.2. The roadmap pages of these four ITRMs are attached in Appendix A. The developers of these four roadmaps include academia, industrialists, and government officers. The contents are analyzed, and the attributes contributed to good content quality are identified.

Table 3.2 Four selected roadmaps for case study analysis

Year	Roadmaps	Origin	Author Type
2007	Mapping of evidence on sustainable development impacts that occur in the life cycles of clothing (Madsen, 2007)	UK	Government
2008	Technology roadmap for Canadian textile industry (Cttgroup, 2008)	Canada	Industry
2009	Industry technology roadmap for the flushable pre-moistened nonwoven wipes industry (Kim, 2009a)	US	Academia
2010	Development of Technology Roadmap for Guangdong Textile and Clothing Industry (Li & Xiong, 2010a)	China	Academia-Industry-Government

The following six steps of content analysis (Section 3.2.1) were used in the assessment of the four roadmaps.

Step 1 – Propose research question

The research question is whether the newly developed ITRM internal assessment model is feasible to assess the quality of content in four selected roadmaps?

Step 2 – Select the unit of analysis

Four global ITRMs for textiles were content analyzed to investigate their success in content and seek certain attributes that bear a relationship to content quality. Four selected ITRMs are shown in Table 3.2. All of the four roadmaps are at the industrial level and are written by authors from academia, industry, and government.

Step 3 – Develop the coding/categorization scheme

Inductive content analysis is recommended when the knowledge is fragmented, whereas deductive content analysis is recommended for theory or model testing (Elo & Kyngäs, 2008; Hsieh & Shannon, 2005; Sandelowski, 1995). For internal assessment of ITRMs, the deductive content analysis was adopted for the theoretical framework. Categorization scheme for deductive content analysis includes a categorization matrix and data coding (Elo & Kyngäs, 2008).

Based on the theoretical framework (Fig. 3.1) and the knowledge framework of ITRM content assessment model (Fig. 3.2), the categorization matrix of assessment criteria is shown in Table 3.3. No time dimension is given in these categories, and they can be applied at any time point to meet varied purposes.

Table 3.3 Categorization matrix for content analysis of ITRMs

Main criteria	**Key attribute**	**Sub-attribute**	**Assessment items**
Internal Legitimacy	1. Internal Legitimacy	Roadmapping methods	definitions for ITRM, roadmapping techniques, and process

		Expert panel	authority level of expert panel
		Research team	authority level of research team
Knowledge framework of ITRM content	2. Value Chain	Value chain	price index and value addition for each industrial segment
	3. Supply Chain	Supply chain	supply and demand status among industrial segments
	4. Innovation Chain	Innovation chain	technology innovation capacity and innovation clusters among industrial segments
	5. Industrial Goals	Industrial gaps	main gaps for industry development
		Research areas	target research areas
		Development strategy	development strategy to achieve industrial goals
		Key projects	key projects to develop
	6. Key Technology	Technology barrier	main technological barriers for the industry
		Objectives of technology	objectives of technologies to develop
		Current status of technology	current status of technologies, such as in mature, advanced or frontier levels
		Key technologies to develop	key technologies to develop in different terms, i.e. short, medium, or long term
	7. Macro Environment	Economics factor	external economic threats/shocks for the industry from structure, conduct, and performance
		Societal challenges	social effects that can influence the industry directly, such as labor force and residential living level
		Environmental protection	impacts on environment and responding solutions for ecological protection and balance
		Resources provision	supply, demands and distributions of resources of raw materials, energy, and others
		Politics, cultures, and lifestyles	key political, cultural and lifestyle elements and their changing trends
		Population feature	key structural features and changing trends of human population
	8. Micro Environment	Infrastructures	current status and future demands of infrastructural facilities and platforms
		Government policies and international	existing international agreements and policies in the nations or regions

		agreements	
		Capital investment	structure and trends of capital investments from governments and industries/regions
		Education and training	status and demands of higher education and professional training

Each of the four ITRMs is reviewed for content and coded for correspondence with or exemplification of the identified categories by using the newly developed categorization matrix and the rules of data coding (Elo & Kyngäs, 2008; Polit & Beck, 2004). Before formal data coding by the experts, a pilot study was carried out to ensure that the corresponding or exemplified content in each ITRM can be coded into the categories. The full content of the four selected ITRMs and the categorization matrix were then sent to the experts, with written instructions and follow-up explanation via video calls, for them to code the relevant content into the corresponding category for each ITRM.

Step 4 – Perform measurement

Scoring with a rubric is more reliable than scoring without it (Jonsson & Svingby, 2007) because different experts may use different criteria in rating the ITRM content. Therefore, the rubrics (Appendix B) are developed and provided for the experts to assess specific content of the ITRMs. The score ranges from 1 (bad performance) to 5 (good performance) for each category. The invited experts coded the ITRM content into the categorization matrix and assessed each category alongside the provided rubrics.

In this research, four experts were invited for content analysis and rating. The criteria of expert selection included: (1) expertise in textile; (2) have experiences in technology roadmapping for textile industry; and (3) have more than 10 years' professional career in textile-related areas. Table 3.4 shows the information of the four invited experts.

Table 3.4 Information of the four invited experts

No.	Expertise	Background	Origin
1	Material science and textile innovation management	Academia	UK
2	Textile testing technology and textile technology industrialization	Academia	Hong Kong
3	Textile engineering and textile project management	Industry Association	Hong Kong
4	Computing science, and simulation and visualization of textile materials	Industry	Mainland China

Step 5 – Check reliability

Interrater reliability refers to the extent to which the independent raters agree on the coding and rating of the content in the same categorization/coding scheme (Lavrakas, 2008). The Interrater reliability is widely accepted as the standard measure for research quality (Kolbe & Burnett, 1991; Lombard et al., 2002) and it is a critical component of the content analysis. In this research, the average pairwise percentage agreement (Lombard et al., 2010) and Cohen's Kappa index (Bakeman, 2000; Dewey, 1983; Lombard et al., 2002) are adopted to determine the interrater reliability. The average percentage agreement is 73.96% and considered reliable (Frey et al., 2000). The Cohen's Kappa is 0.625 and regarded as substantially reliable (Landis & Koch, 1977).

Step 6 – Report results

The experts' scores, as nonparametric data, are transformed to ranks (Section 3.2.2). Each ITRM is scored by the four experts respectively so that each sub-attribute ranks from 1 to 16. The results are reported in the below section in detail.

3.4 Results

3.4.1 Content analysis

3.4.1.1 Internal legitimacy

The median and range of the ranks for the three sub-attributes of internal legitimacy for the four ITRMs are presented in Table 3.5.

Table 3.5 Results of ranks (median and range) for sub-attributes of internal legitimacy

Sub-attribute	**UK**	**Canada**	**US**	**China**
Roadmapping methods	7.50 (6.50)	7.50 (0.00)	15.00 (7.50)	7.50 (0.00)
Expert panel	11.00(10.00)	3.50 (7.50)	11.00 (7.50)	11.00 0.00)
Research team	6.25 (10.50)	9.00 (0.00)	3.50 (0.00)	14.00 0.00)
Overall score of internal legitimacy	8.25 (9.00)	6.67 (2.50)	8.58 (2.50)	10.83 0.00)

Among the four ITRMs rated, the Canadian roadmap (see Fig. 3.5) received the lowest quality score 6.67 out of 16 for the internal legitimacy, because it failed to address the definition and methodology of roadmapping and only invited nine stakeholders from Canadian textile companies as expert panels. The ITRM for the US received the best rating for roadmapping methods but the worst rating for authority level of the research team. The Chinese ITRM was ranked the highest for the internal legitimacy average because of the diversified and reputable members in both expert panel and research team. The UK one received a score of 8.25 out of 16, and its main weakness was a lack of reputable participants from academia and governmental departments.

3.4.1.2 Value chain, supply chain, and innovation chain

Based on the original expert scores, the rating of the value chain for all the four ITRMs is unsatisfactory. In the US and Chinese ITRMs, the information of the value chain was fragmented and coded from the sections of supply and innovation chains.

The ranking order for the quality of supply chain was the Canadian, Chinese, UK, and the US ITRMs. In these ten years, collecting data and information about the supply and demand of an industry from various databases and websites was possible. The main challenge is how to filter and analyze the huge amount of information.

In the ratings for the innovation chain, the US ITRM ranked the lowest, because it only carried out a patent search for technology and innovation analysis. The content of the innovation chain is used as an important attribute for roadmaps.

3.4.1.3 Industrial goals and key technology

The median and range for sub-attributes of industrial goals and key technology for the four ITRMs are presented in Table 3.6. The Chinese and UK ITRMs ranked the top two for the key projects and current status of technology, showing the benefits of using diversified databases.

Table 3.6 Results of ranks (median and range) for the sub-attributes of industrial goals and key technology

Key attribute	**Sub-attribute**	**UK**	**Canada**	**US**	**China**
Industrial goals	Industrial gaps	6.00 (7.50)	6.00 (0.00)	6.00 (0.00)	13.50 (2.50)
	Research areas	6.00 (7.50)	6.00 (0.00)	6.00 (0.00)	13.50 (2.50)
	Development strategy	8.50 (0.00)	8.50 (0.00)	8.50 (0.00)	8.50 (0.00)
	Key projects	9.00 (8.00)	5.00 (0.00)	5.00 (8.00)	13.00 (0.00)
Key technology	Technology barrier	10.50 (13.50)	10.50 (0.00)	2.50 (2.50)	10.50 (0.00)
	Objectives of technology	9.00 (0.00)	9.00 (0.00)	5.25 (7.50)	9.00 (7.00)
	Current status of technology	10.50 (6.00)	7.50 (5.00)	2.50 (5.00)	13.50 (0.00)
	Key technologies to develop	7.50 (8.00)	7.50 (0.00)	7.50 (0.00)	7.50 (8.00)

3.4.1.4 Macro and micro environment

The median and range for the sub-attributes of macro and micro environment for the four ITRMs are shown in Table 3.7.

Table 3.7 Results of ranks (median and range) for the sub-attributes of macro and micro environment

Key attribute	**Sub-attribute**	UK	Canada	US	China
Macro environment	Economics Factor	9.75 (7.50)	6.00 (0.00)	6.00 (5.00)	13.50 (0.00)

	Societal Challenges	7.25 (7.50)	11.00 (7.50)	3.50 (7.50)	11.00 (5.00)
	Environmental Protection	10.00(14.00)	4.50 (5.00)	7.00 (0.00)	13.00 (0.00)
	Resources Provision	12.00 (11.50)	8.25 (7.50)	4.50 (7.50)	8.25 (7.50)
	Politics, Cultures, and Lifestyles	9.50 (0.00)	9.50 (8.00)	9.50 (8.00)	9.50 (0.00)
	Human Population Feature	7.25 (10.50)	13.50(0.00)	5.00 (0.00)	8.50 (5.00)
Micro environment	Infrastructures	7.50 (12.00)	14.50 (3.00)	2.50 (5.00)	7.50 (4.00)
	Policies and Agreements	11.00 (14.50)	11.00 (6.50)	4.50 (3.00)	11.00 (0.00)
	Capital Investment	8.50 (11.00)	14.00 (0.00)	8.50 (5.50)	3.00 (5.50)
	Education & Training	11.00 (7.50)	11.00 (0.00)	3.50 (2.50)	11.00 (0.00)

The UK, Canadian, and Chinese ITRMs received both very good and unsatisfactory scores for different sub-attributes, and the US ITRM was rated with quite low scores for most of these attributes. These results revealed that the content construction of an ITRM has not yet been effectively developed.

3.4.2 Quality measurement

3.4.2.1 Quality scores

After analyzing the quality of each sub-attribute (Section 3.4.1), the newly proposed methods and equations (Section 3.2.2) were also used to analyze the overall quality of the four ITRMs. The quality scores (Q_i) of the eight key attributes for each ITRM are illustrated in box plots (median and range) in Figs. 3.5–3.8.

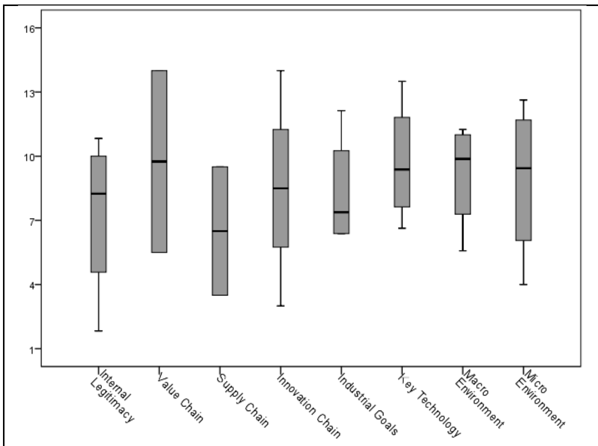


Fig. 3.5 Quality scores of eight key attributes in the UK ITRM

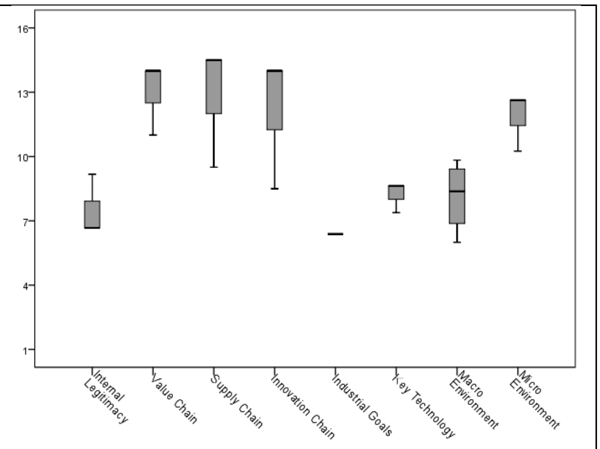


Fig. 3.6 Quality scores of eight key attributes in the Canadian ITRM

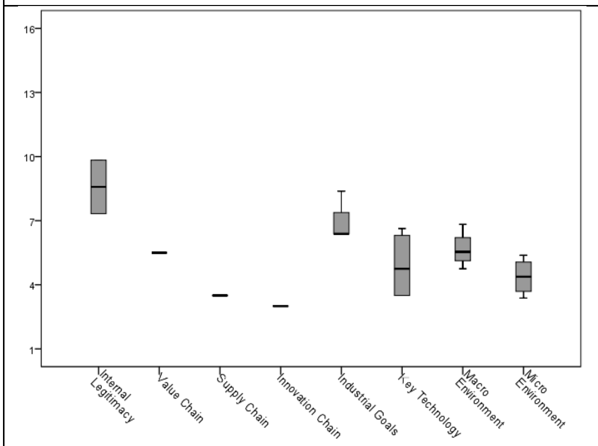


Fig. 3.7 Quality scores of eight key attributes in the US ITRM

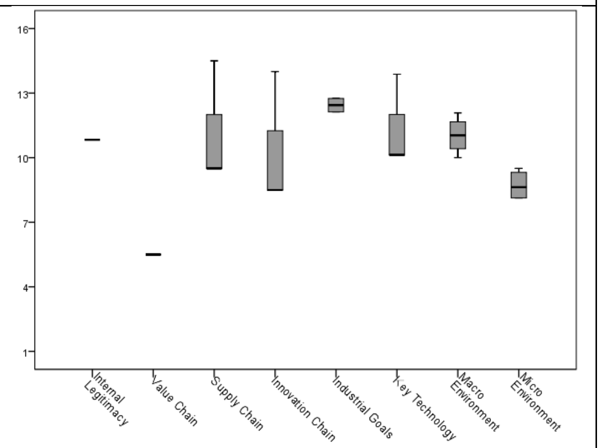


Fig. 3.8 Quality scores of eight key attributes in the Chinese ITRM

Though rubrics had been provided, variance still existed, especially for the UK roadmap. Brief interviews have been conducted with the two experts who gave the highest and lowest rating for this roadmap respectively. One expert thought the information collected in the UK roadmap was very comprehensive. Even though only desk review was conducted, he gave high scores to many of the attributes. The other expert explained that he gave low scores to the UK roadmap because it had not formed any formal expert committee to generate new ideas and was over relied on the second-hand resources.

A radar diagram for a comparison of the four roadmaps against each key attribute is presented in Fig. 3.9.

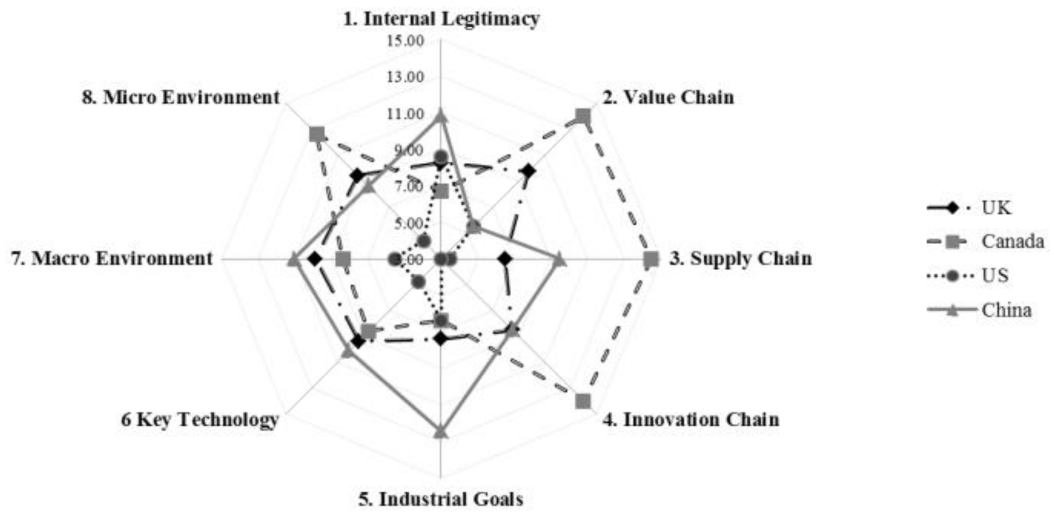


Fig. 3.9 Quality scores (median) for each attribute in the four ITRMs

The area of Canadian ITRM was the largest, because it ranked the highest in value chain, supply chain, innovation chain, and micro environment analysis. However, for the other two attributes, namely, internal legitimacy and industrial goals, it ranked the lowest. Amongst the four ITRMs, the US one ranked the worst and occupied the smallest area in Fig. 3.9. The US ITRM ranked the lowest in seven key attributes out of eight, except internal legitimacy. The Chinese ITRM had best quality scores of internal legitimacy, industrial goals, key technology, and macro environment analysis. The UK ITRM ranked medium for all the key attributes.

Fig. 3.10 presents the quality scores (median and range) of the market and technology forces in the four ITRMs.

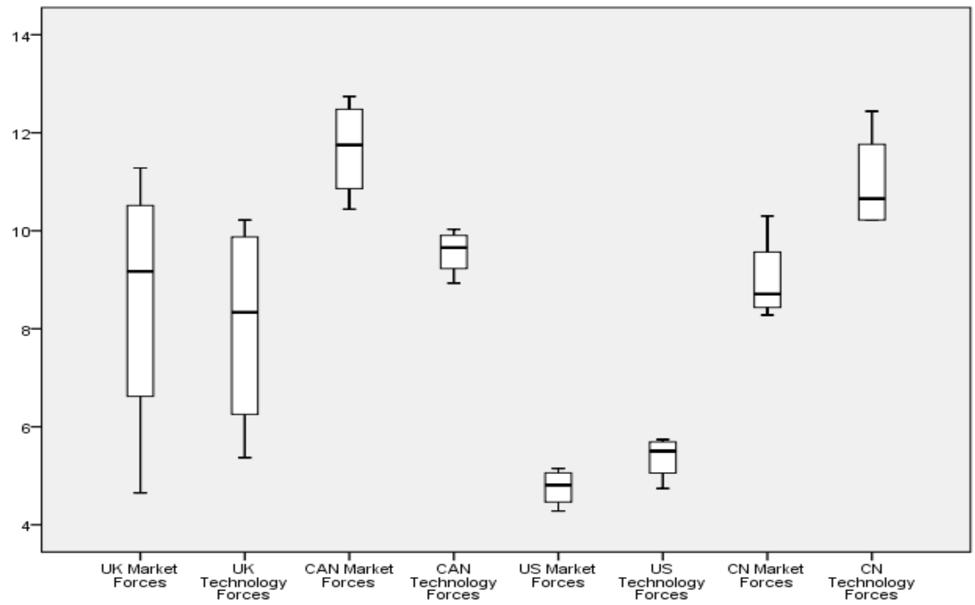


Fig. 3.10 Quality scores (median + range) of the market and technology forces of the four ITRMs

The Canadian ITRM received best quality score for market forces, and the Chinese one best for technology forces. Moreover, the UK and Canadian ITRM had better quality scores of market forces than did technology forces, and the US and Chinese ones ranked better for technology forces than for market forces.

3.4.2.2 Internal deficiency index

The calculated results (median and range) of internal deficiency and relative internal deficiency are plotted in Fig. 3.11. Table 3.8 shows the overall results (median + range) of quality measurement for the four ITRMs.

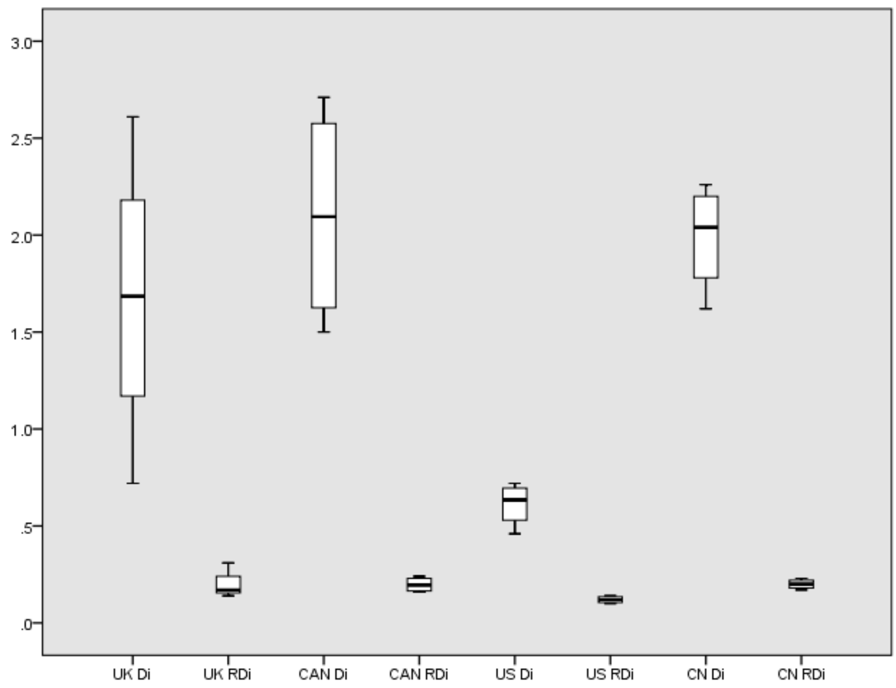


Fig.3.11 Results (median + range) for internal deficiency and relative internal deficiency of the four ITRMs

Table 3.8 Overall results (median + range) of quality measurement for the four ITRMs

ITRM	Origin	Overall quality score (Q_O)	Internal deficiency (D_I)	Relative internal deficiency (R_{DI})
Mapping of evidence on sustainable development impacts that occur in the life cycles of clothing (Madsen, 2007)	UK	9.20(5.17)	1.69(1.89)	17% (0.17)
Technology roadmap for Canadian textile industry (Cttgroup, 2008)	Canada	10.41(1.84)	2.10(1.21)	20% (0.08)
Industry technology roadmap for the flushable pre-moistened nonwoven wipes industry (Kim, 2009a)	US	5.41(1.06)	0.63(0.26)	12% (0.04)

Development of Technology Roadmap for Guangdong Textile and Clothing Industry (Li & Xiong, 2010a)	China	9.83(1.77)	2.04(0.64)	20% (0.06)

The values of internal deficiency and the relative internal deficiency were larger in the Canadian and Chinese ITRMs, although they ranked top two for overall quality. The bars show that the content of market and technology forces were not well developed in balance in the four ITRMs examined.

The UK ITRM, initiated by the governmental department, collected sufficient information on market and technology status for the industry from different databases of industry, academia, and government. However, the ITRM only presented the second-hand sources without incorporating new knowledge from the roadmapping processes.

The Canadian ITRM, initiated by a national industrial association, performed extremely well on the information and analysis of industrial statuses, such as value chain, supply chain, innovation chain, and micro environmental analysis. However, its strategic decisions in close relation to technology forces, such as industrial goals and key technology to develop, needed further improvement.

The US roadmap, as an academic thesis, had strength in methodology, but the analysis of the industrial status and strategic decisions was not sufficient. Although the relative internal deficiency of the US ITRM was the smallest, it seemed not the result of awareness of balanced development of market and technology forces, because of the poor ranks for the content quality of both market and technology forces.

The Chinese roadmap, as a cooperative work of industry, academia, and government, had generally good ratings across various attributes except for value chain. As opposed to the Canadian ITRM, the Chinese one received good rankings on key attributes in close relation to technology forces rather than market forces.

3.5 Discussion

Based on the assessments of the four ITRMs investigated, the content in all the four ITRMs were not systematically organized, and some relevant attributes were not mentioned or were only partially covered. These results revealed a lack of systematic frameworks for ITRM content presentation and the authors might only present the content with easy access.

Moreover, different types of organizations focused on different attributes of an ITRM's content. For example, the governmental department (UK roadmap) focused more on macro-environmental analysis, such as environmental protection, resources, and policies. By contrast, the industrial association (Canadian roadmap) emphasized attributes in relation to the conditions for realizing industrial goals, such as infrastructure, capital investment, and education and training. The organizational backgrounds also affected the content quality. For industry-status-related content, such as value, supply, and innovation chains and micro environment analysis, research team and expert panels from the industry (Canadian roadmap) had superior performance because they had more direct and sensitive judgments on actual industrial statuses. For technology-planning-related content and macro environment analysis, research team, and expert panels from multiple organizations in academia, industry, and governmental departments had improved performance, because multi-organizational backgrounds could focus on the overall situations and generate collaborative opinions across various organizations rather than interest of particular entities.

Different data sources also affected the quality of information collection and analysis. The Canadian roadmap used the database of the Canadian Textile Industry Association as a source, and the ITRM attributes that related to industrial development such as infrastructures, capital investment, and educational human resources had better scores. The Chinese roadmap used the database "Web of Knowledge" and "SCI-Finder" to explore the updated status of technology and innovation, and it received high scores in the relevant attributes. The UK roadmap was created by desk research on secondhand information but still received medium scores on all the attributes.

This research aims to propose systematic methods for ITRM assessment, and equal weighting was adopted for each attribute. Different organizations have different objectives of a roadmap and emphasis on different attributes and sub-attributes; therefore, different weightings can be applied based on the provided assessment methods.

3.6 Recommendations

3.6.1 Five success factors

Based on the assessment framework and results, the following five success factors are recommended to aid in the organizing and writing of ITRM, particularly for the textile industry. With this experience, more case studies in other industries can be performed to widen the applications of the proposed internal assessment model.

(1) Methodology of industry technology roadmapping

As a future development planning tool, industry technology roadmapping has been developed, amended, and applied in various areas with different objectives. Choosing suitable methods for different levels (industry or corporate), roadmapping techniques and processes is necessary to adapt different objectives for roadmaps.

(2) Multi-organizational background

A research team and expert panels that included renowned experts in balanced technology, business, and governing areas of the target industry worldwide is recommended. Usually, ideas about the overall industrial trends as well as specific technology development can be generated from expert forums, workshops, interviews and so forth, depending on the decisions made by the research team.

(3) Systematic presentation of ITRM content

For the ITRM to have a clear and comprehensive analysis of the current status of the targeted industry is important, thereby ensuring that the audience gets the updated knowledge of the development of the industry. Presenting data and analysis from three aspects, namely, value, supply, and innovation chains, can provide a dynamic vision of the entire industry rather than only fragmented information.

Setting industrial goals and prioritizing key technologies/barriers for various developing periods are the crucial tasks for ITRMs, and should be carefully generated to cover a range of industrial participants (academia, industry, and government) to ensure the implementation effectiveness.

Industrial development cannot be isolated from the macro environment. To avoid predictable risks and utilize potential advantages, analyzing the economic factors, societal challenges, environmental protection, resources provision, politics and culture, and population features is necessary. To connect the macro environment with the target industrial status, the micro environment including infrastructures, policies, and agreements, capital investment, education, and training is also recommended for investigation.

(4) Balanced content for market and technology forces

The core task for an ITRM is to minimize the gaps between the market demands and the technology and innovation development. Therefore, the content for current and potential market forces and technology forces should be developed in balance. The more well-matched market and technology forces are, the smaller internal deficiency is and the better the target industry develops.

(5) Appropriate databases

Using corresponding databases for collecting different types of information is helpful in improving the quality of presented data and analysis. For example, industry association databases, customer databases, national statistics yearbooks, governmental statistics, and international organizations' databases can be valuable for industrial status and macro and micro environmental analysis.

Scientific tools, such as “Web of Science,” “Web of Knowledge,” “Scopus,” “Sci-Finder,” and “Google Scholar” can be adopted for technology and innovation analysis.

3.6.2 Advantages over the previous suggestions of success factors

Phaal et al. (2001b) identified ten success factors including “clear and effective process for developing ITRM,” “effective tools/techniques/methods,” and “right people/functions were involved;” these factors are similar to our first two recommendations. Their success factors were generated from the surveys on the roadmapping process, whereas our success factors were revealed from the results of systematic assessment of four actual ITRMs.

Jeffrey et al. (2013) suggested eight success factors for ITRM based on the assessment results of four ITRMs in the renewable energy sector. Furthermore, two success factors, namely, “having the right people/author in place” and “robust method for developing the roadmap,” were similar to our first two recommendations. People with multi-organizational backgrounds were involved in both studies, but Jeffery et al. did not mention the expert panels.

The recommended success factors (1) and (2) also agree with those proposed by the previous research (Gerdsri et al., 2009; Jeffrey et al., 2013; Phaal et al., 2001b). Success factors (3), (4), and (5) are newly emerged from the analysis of internal quality assessment results of four ITRMs in textiles. The advantage is that the five success factors are recommended based on internal quality of the ITRM content; thus, they can provide more practical guidelines for ITRM content construction.

3.7 Conclusion

The assessment of the success of an industry technology roadmap is a complex process. To maximize the effectiveness of an ITRM, the content of an ITRM should be elaborated upon, thereby leading to more effective processes and roadmapping techniques.

The essence of the proposed internal assessment model is a theoretical framework that connects different content attributes. In addition to assessment, this framework can be used for systematic presentation of ITRM content. The concept of internal deficiency has been initially developed to emphasize the balanced integration between market forces and technology forces in an ITRM, and relevant indices have been also developed to open a new chapter in the quantitative assessment of roadmaps. The findings of this study can help practitioners to develop an effective ITRM with clear guidelines and a knowledge framework.

By focusing on content quality, this proposed model is limited to internal assessment of roadmaps. Future studies of external assessment on actual performance of roadmaps are presented in Chapter 4.

Chapter 4 External Assessment Model and Analysis

As mentioned in the previous chapters, the quality of ITRM is yet to be evaluated well (Carvalho et al., 2013; Vatananan & Gerdsri, 2012). Only a few studies have assessed the actual achievements of ITRM (Jeffrey et al., 2013; Phaal et al., 2001b). Chapter 3 has shown the content quality assessment of the four ITRMs using an internal assessment model. This chapter focuses on the follow-up assessment of the actual performance of the same four ITRMs using an external assessment model. Detailed guidelines for an effective ITRM are recommended.

4.1 External Assessment Model

The external assessment model was designed to evaluate the performance of an ITRM in terms of the difference between the roadmap planning and external actual trends within the study period. Similar to the internal assessment model in Chapter 3, a theoretical framework with a set of external assessment attributes has been developed. Various indicators have been selected against each assessment attribute, and quantitative measurements for the assessing the external performance of an ITRM have been initially developed.

4.1.1 Theoretical framework

Except for the internal legitimacy, the same seven key attributes in Chapter 3 are assessed using a theoretical framework for ITRM external assessment (Fig. 4.1).

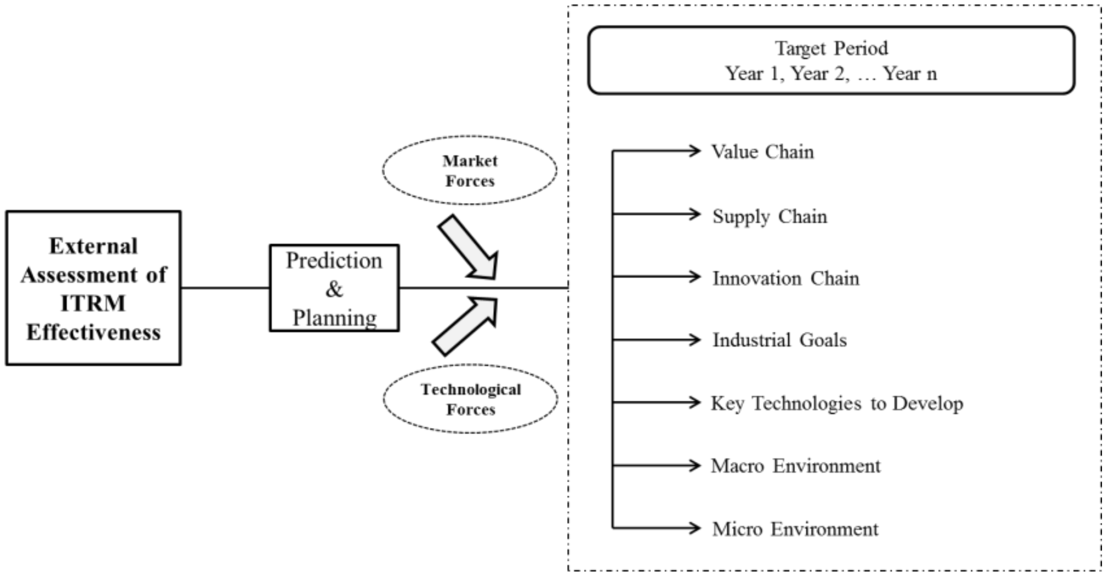


Fig. 4.1 Theoretical framework for external assessment of ITRM

In assessing the internal contents or external performance, the key attributes in Fig. 4.1 shares the same dynamic industrial contexts. However, the external assessment analyzes the changes in a set period, whereas the internal assessment only focuses on the static contents presented in the ITRM. Fig. 4.2 shows the knowledge framework of an ITRM external assessment model. By omitting the internal legitimacy and adding the realization of industrial goals and achievement of key technology from Fig. 3.2, the attributes remain the same for internal and external assessments.

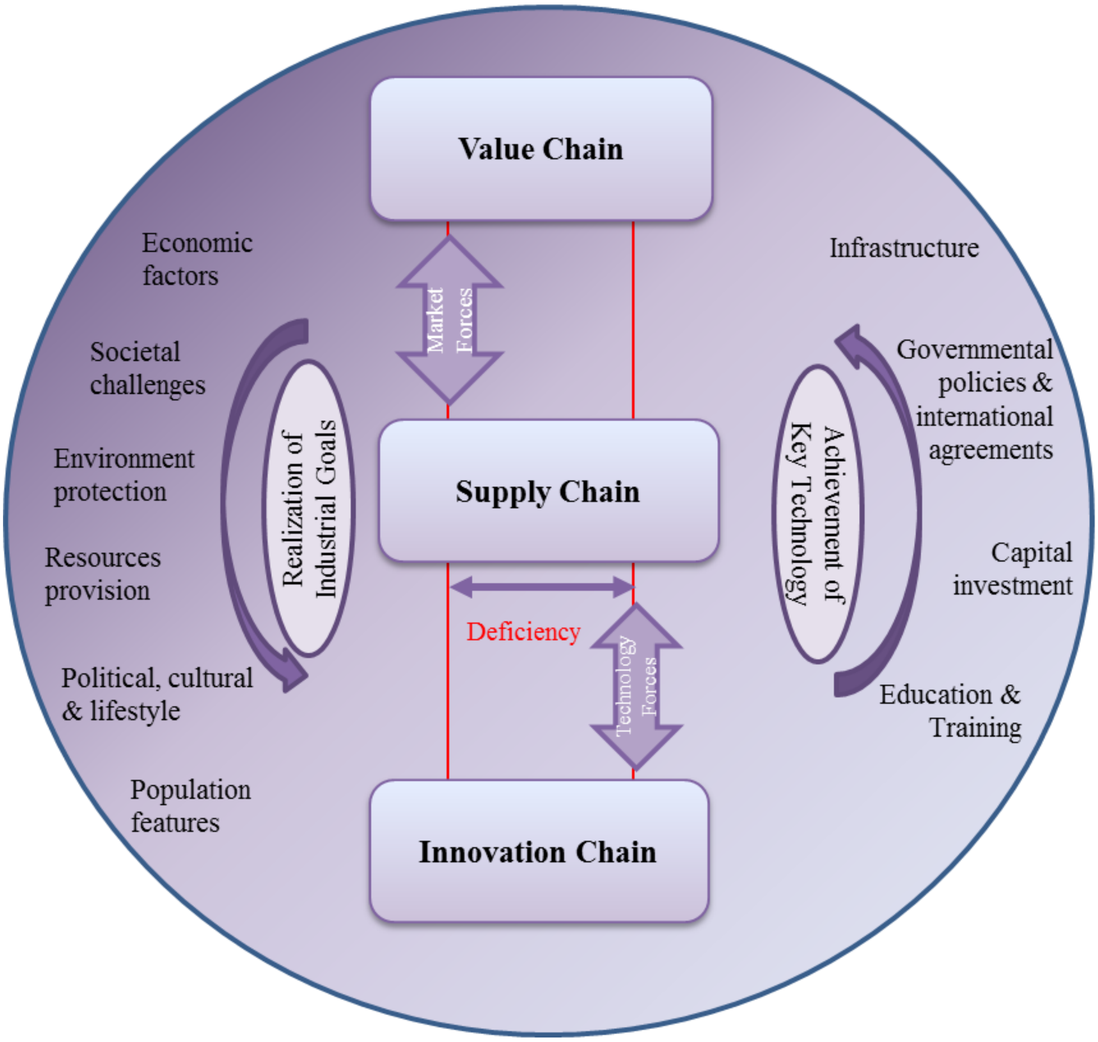


Fig. 4.2 Knowledge framework of ITRM external assessment model

The definitions and linkages among the attributes are presented in Section 3.1.2. The external assessment model investigates the actual performance of each attribute. If the predictions in the roadmap conform to the actual development trends of the industry, then ITRM performs well. A list of assessment indicators is selected in Section 4.1.2. on the basis of the internal content assessment scopes of key attributes, including value chain, supply chain, innovation chain, industrial goals, key technology, macro environment analysis, and micro environment analysis (except the attribute internal legitimacy representing the facts of an ITRM rather than actual development) in Fig. 3.1.

As industry development is a complicated process with numerous activities, the actual industrial developments cannot be quantified as direct measurement of an ITRM. Therefore, in this study, the conformance between actual development trends and original predictions in the technology roadmap is regarded as the overall performance of a roadmap. To date, the concepts and methods for accurate predictions are yet to be studied comprehensively. In this work, the external deficiency between market and technology forces is first established for roadmap performance assessment. The detailed measurement is presented in Section 4.1.3.

4.1.2 Assessment indicators

An indicator provides evidence that a certain condition exists or certain results have or have not been achieved (Brizius & Campbell, 1991). Indicators enable a result-based assessment toward the achievement of intended goals (Horsch, 1997). To select appropriate indicators for the seven attributes (Fig. 4.1), internal assessment scores for the attributes are referred, and content analysis of existing literature is adopted. The indicator sets for each facet should be specific and focused (Msh, 1995). Table 4.1 presents a summary of 20 specific indicators for external ITRM assessment of seven key attributes with references.

The indicators are measured based on the actual data available in the ITRMs.

Table 4.1 Assessment criteria and references of the 20 indicators for ITRM external assessment

	Indicator	Accuracy of predicted development of attribute	Reference
1	Value added (% of GDP)	value chain	(Gereffi et al., 2001; Johnson & Noguera, 2012; Kaplinsky & Morris, 2001; Wang et al., 2017)
2	Exportation amount	supply chain	(Baldwin, 2011; Ling-Yee & Ogunmokun, 2001; Stock & Lambert, 2001)
3	Importation amount	supply chain	(Arntzen et al., 1995; Baldwin & Lopez‐Gonzalez, 2015; Blalock & Veloso, 2007)
4	Number of patents relevant technology and innovation	innovation chain	(Lahiri, 2010; Merges, 1988; Miller et al., 2007)
5	Number of research papers relevant technology and innovation	innovation chain	(Li & Xiong, 2010b; Perkmann & Walsh, 2007; Robinson et al., 2013)
6	Number of conference topics relevant technology and innovation	innovation chain	(Keegan & Turner, 2002; Mateik, 2010; Yixin, 2011)
7	Number of official documents related to the proposed research areas	industrial goals	(Austin & Bobko, 1985; Latham & Locke, 2007; Van Lamsweerde, 2004)
8	Number of official documents related to the proposed key projects	industrial goals	(Cooper, 1979; Koskela & Howell, 2002; Ronan et al., 1973)
9	Number of patents, research paper and conference topics of the proposed technology gaps	key technologies	(Carpenter & Narin, 1981; Griliches, 2007; Mowery et al., 2015; Smith, 2005)
10	Number of patents, research paper and conference topics of the proposed key technologies	key technologies	(Carpenter & Narin, 1981; Griliches, 2007; Mowery et al., 2015; Smith, 2005)
11	Changes of GDP growth	macro environment	(Beck, 2000; Dunning & Narula, 2003; Hillebrandt, 1985)
12	Changes of labor cost	macro environment	(Dong & Putterman, 2003; Oi, 1962)
13	Changes of the searching number of proposed environmental problems and solutions searched	macro environment	(Habert et al., 2011; Ross, 1996)
14	Changes of provision of raw materials mentioned	macro environment	(Schoer et al., 2012; Wiedmann et al., 2015)
15	Changes of household final consumption expenditure	macro environment	(Hall, 1988; Lucas Jr, 2003; Rots & Maduko, 2014)
16	Changes of population growth	macro environment	(Black & Henderson, 1999; Utterback & Suárez, 1993)
17	Changes of searching number of proposed facilities and platforms searched	micro environment	(Jain & Sekar, 2000; Kirchain & Kimerling, 2007)
18	Changes of searching number of proposed polices and agreements searched	micro environment	(Lewis & Wiser, 2007; Wilensky, 2015)
19	Changes of R&D expenditures in the textile industry	micro environment	(Foxon et al., 2005; Hansen & Birkinshaw, 2007; Roper et al., 2008)
20	Changes of number of dissertations in textile-related areas	micro environment	(Borrell-Damian, 2009; Precision Consultancy Business & Council, 2007)

4.1.3 Measurement

After establishing the indicator sets for external assessment of ITRMs, the measurement steps and detailed methods are illustrated below.

Step 1 – Data collection

Data for each indicator are collected from relevant databases during the investigation period. The publication year of the ITRM is set as the start year because the analysis and predictions are usually conducted before an ITRM is published, and are effective for the following five to ten years, or even longer, that is, twenty years. The end of the investigation period depends on the research objectives or data availability.

Certain indicators in Table 4.1 are unavailable due to various situations in different industries. Rational Pharmaceutical Management Project (Msh, 1995) suggested that the designed indicators evolve with corresponding objectives. Therefore, adapting changes to the proposed indicator set based on the available industrial data can be made.

Step 2 – Data normalization

As unit measurements of the data for each indicator are different, all data groups are scaled between 0 and 1 by the min-max normalization technique using Equation 1 below,

$$z = \frac{x - x_{min}}{x_{max} - x_{min}}, \quad (1)$$

where z is the normalization value, x is the original value, x_{min} is the minimum value within the same original data group, and x_{max} is the maximum value within the same original data group.

Step 3 – Calculation of *change*

With the normalized data, the sum of changes within each investigated year is calculated by Equation 2,

$$C = (x_{o+1} - x_o) + (x_{o+2} - x_o) + \ldots + (x_n - x_o), \quad (2)$$

where C is the sum of data changes in each investigated year compared to the data in the starting year with normalized value, x_o is the normalized data in the starting year, and x_n is the normalized data in the nth year after the starting year.

Step 4 – Conformance between actual trend and original prediction in roadmap

The actual trend is an increase if C is positive and a decrease if C is negative. The original predictions derived from the ITRM are compared with the values of C to investigate whether the actual trends conform to the predictions in the ITRM.

Ordinal measures are used for the conformance results of the indicators (y_n).

If the actual trends conform with the predictions, a score of 1 is assigned to the corresponding indicator and 0 when the actual trends are different from the predictions.

Step 5 – Calculation of the performance scores

The performance score P_i is calculated with the average of conformance results of relevant indicators (Equation 3) for the ith key attribute listed in Table 4.1,

$$P_i = \sum y_{ni} / m_i, \quad (3)$$

where P_i represents the performance score of the ith key attribute, y_{ni} is the conformance result of each indicator for the ith key attribute, and m_i is the total number of the corresponding indicator for the ith key attribute.

With the results of P_i, the performance score of all market-force-related attributes and all technology-force-related attributes and the overall performance of ITRM can be calculated by Equations 4, 5, and 6, respectively.

$$P_{MF} = (P_1+P_2+P_6+P_7) / 4, \quad (4)$$

where P_{MF} represents the performance score of market-force-related attributes and P_1, P_2, P_6, and P_7 represent the performance score of the value chain, supply chain, macro environment, and micro environment analysis, respectively.

$$P_{TF} = (P_2+P_3+P_4+P_5) / 4, \quad (5)$$

where P_{TF} represents the performance score of technology-force-related attributes and P_2, P_3, P_4, and P_5 represent the performance score of the supply chain, innovation chain, realization of industrial goals, and achievement of key technologies, respectively.

$$P_O = \sum P_i / 7, \quad (6)$$

where P_O represents the overall performance score of an ITRM and P_i is the performance score of the ith key attribute, where i = 1, 2,…,7.

Step 6 – Calculation of the external deficiency

External deficiency (D_E) is the absolute value of the difference in performance scores between the market forces and technology forces, as shown in Equation 7.

$$D_E = | P_{MF} - P_{TF} | \quad (7)$$

The relative external deficiency (R_{DE}) in percentage is calculated by Equation 8.

$$R_{DE} = D_E / [(P_{MF} + \mathrm{P}_{TF})/2] *100\% \quad (8)$$

4.2 Assessment of ITRMs

The external assessment model discussed in Section 4.1 is used to assess the actual performances of the four textile ITRMs (Table 3.2) that were internally assessed in Chapter 3. The most recent of the four ITRMs was published in 2010 and majority of the available data were up to 2014, when the assessment was conducted; hence, each ITRM is assessed based on a five-year investigation period.

Following the six steps described in Section 4.1.3, the original data of each indicator for the four roadmaps in five years, have been collected in Tables 4.3 to 4.6.

Table 4.3 Collected data for external assessment of the UK ITRM

	Indicator	Original data					Database
		2007	2008	2009	2010	2011	
1	Value added (% of GDP)	21.542	21.144	19.94	20.113	20.307	(Worldbank, 2017d)
2	Exportation amount (USD Million)	11325	10780	8762	9591	11182	(Wits, 2017e)
3	Importation amount (USD Million)	36297	35931	30658	32718	36470	(Wits, 2017f)
4	Number of patents	18	14	19	15	18	(Scifinder, 2017)
5	Number of research papers	490	418	507	491	514	(Scopus, 2017)
6	Number of conference topics	0	17	2	9	9	(Scopus, 2017)
7	Number of official documents related to the proposed research areas	12	18	19	27	24	(Scifinder, 2017)
8	Number of official documents related to the proposed key projects	281	211	255	229	211	(Scifinder, 2017)
9	Number of patents, research paper and conference topics of the proposed technology gaps	20	17	26	27	28	(Scifinder, 2017)
10	Number of patents, research paper and conference topics of the proposed key technologies	208	160	142	167	162	(Scifinder, 2017)
11	GDP growth (annual %)	2.556	-0.627	-4.328	1.915	1.509	(Worldbank, 2017a)
12	Labor cost (USD Million)	7238.7	6547.6	4934.9	5023.2	5281.6	(Oecd, 2017c)
13	Number of proposed environmental problems and solutions searched	151	101	117	159	171	(Scopus, 2017)
14	Provision of raw materials mentioned (cotton production in the US, 1000 bales)	19206.9	12825.4	12183	18101.8	15573.2	(Statista, 2015)
15	Household final consumption expenditure (% of GDP)	64.699	65.343	65.71	65.212	64.924	(Worldbank, 2017b)
16	Population growth (annual %)	0.779	0.787	0.756	0.784	0.782	(Worldbank, 2017c)
17	Number of proposed facilities and platforms searched	64	70	91	99	118	(Scopus, 2017)
18	Number of proposed policies and agreements searched	61	67	83	90	88	(Scopus, 2017)
19	R&D expenditures in the textile industry (USD Million)	19.21	15.32	10.42	10.8	13.1	(Oecd, 2017a)

20	Number of dissertations in textile-related areas	0	0	0	0	0	(Scifinder, 2017)

Table 4.4 Collected data for external assessment of the Canadian ITRM

	Indicator	Original data					Database
		2008	2009	2010	2011	2012	
1	Value added (% of GDP)	31.675	27.221	28.551	29.375	28.884	(Worldbank, 2017d)
2	Exportation amount (USD Million)	3248	2631	3024	3251	3247	(Wits, 2017a)
3	Importation amount (USD Million)	11933	10575	11881	13380	13331	(Wits, 2017b)
4	Number of patents	3	11	7	8	7	(Scifinder, 2017)
5	Number of research papers	238	265	280	329	302	(Scopus, 2017)
6	Number of conference topics	4	2	2	5	15	(Scopus, 2017)
7	Number of official documents related to the proposed research areas	4	7	12	9	4	(Scifinder, 2017)
8	Number of official documents related to the proposed key projects	131	131	156	138	74	(Scifinder, 2017)
9	Number of patents, research paper and conference topics of the proposed technology gaps	159	131	154	133	141	(Scifinder, 2017)
10	Number of patents, research paper and conference topics of the proposed key technologies	164	162	143	162	104	(Scifinder, 2017)
11	GDP growth (annual %)	1	-2.95	3.084	3.141	1.745	(Worldbank, 2017a)
12	Labor cost (USD Million)	2319.9	1964.2	2028.9	2087.4	2135.8	(Oecd, 2017c)
13	Number of proposed environmental problems and solutions searched	8	4	19	19	23	(Scopus, 2017)
14	Provision of raw materials mentioned (textile raw material import, US dollar million)	4156	3459	4041	4348	4501	(Oecd, 2017b)
15	Household final consumption expenditure (% of GDP)	54.377	57.441	56.853	55.796	55.934	(Worldbank, 2017b)
16	Population growth (annual %)	1.082	1.145	1.114	0.988	1.18	(Worldbank, 2017c)

17	Number of proposed facilities and platforms searched	11	7	22	20	20	(Scopus, 2017)
18	Number of proposed polices and agreements searched	81	79	104	120	109	(Scopus, 2017)
19	R&D expenditures in the textile industry (USD Million)	68.77	67.41	59.78	66.94	48.07	(Oecd, 2017a)
20	Number of dissertations in textile-related areas	1	3	1	4	1	(Scifinder, 2017)

Table 4.5 Collected data for external assessment of the US ITRM

	Indicator	Original data					Database
		2009	2010	2011	2012	2013	
1	Value added (% of GDP)	20.216	20.391	20.63	20.544	20.502	(Worldbank, 2017d)
2	Exportation amount (USD Million)	1248	1537	1735	1815	1934	(Franken, 2013; Mayberry, 2016)
3	Importation amount (USD Million)	658	849	907	963	1050	(Franken, 2013; Mayberry, 2016)
4	Number of patents	125	127	114	87	96	(Scifinder, 2017)
5	Number of research papers	1177	1379	1401	1447	1427	(Scopus, 2017)
6	Number of conference topics	28	49	58	78	40	(Scopus, 2017)
7	Number of official documents related to the proposed research areas	2	1	1	0	0	(Scifinder, 2017)
8	Number of official documents related to the proposed key projects	3315	3636	2975	2435	2760	(Scifinder, 2017)
9	Number of patents, research paper and conference topics of the proposed technology gaps	1	1	1	1	0	(Scifinder, 2017)
10	Number of patents, research paper and conference topics of the proposed key technologies	709	680	664	638	588	(Scifinder, 2017)
11	GDP growth (annual %)	-2.776	2.532	1.601	2.224	1.677	(Worldbank, 2017a)
12	Labor cost (USD Million)	18	18.5	19	19.2	19.4	(Tradingeconomics, 2017)
13	Number of proposed environmental problems and solutions searched	0	3	0	2	0	(Scopus, 2017)
14	Provision of raw materials mentioned	36559	28400	47957	50690	54400	(Oerlikon, 2010; Statista, 2017)

	(Global synthetic fiber production, 1000 metric tons)						
15	Household final consumption expenditure (% of GDP)	68.293	68.176	68.884	68.403	68.066	(Worldbank, 2017b)
16	Population growth (annual %)	0.877	0.836	0.764	0.762	0.737	(Worldbank, 2017c)
17	Number of proposed facilities and platforms searched	11	10	14	10	19	(Scopus, 2017)
18	Number of proposed polices and agreements searched	5	16	11	17	13	(Scopus, 2017)
19	R&D expenditures in the textile industry (USD Million)	428	489	634	560	662	(Oecd, 2017a)
20	Number of dissertations in textile-related areas	26	14	15	19	17	(Scifinder, 2017)

Table 4.6 Collected data for external assessment of the Chinese ITRM

	Indicator	Original data					Database
		2010	2011	2012	2013	2014	
1	Value added (% of GDP)	46.396	46.401	45.274	44.008	43.103	(Worldbank, 2017d)
2	Exportation amount (USD Million)	199534	240540	246094	274010	287650	(Wits, 2017c)
3	Importation amount (USD Million)	29578	37588	40865	40418	35973	(Wits, 2017d)
4	Number of patents	155	230	366	694	2068	(Scifinder, 2017)
5	Number of research papers	1004	1966	1320	1910	1682	(Scopus, 2017)
6	Number of conference topics	2	672	144	606	1468	(Scopus, 2017)
7	Number of official documents related to the proposed research areas	3992	4637	5788	6729	8318	(Scifinder, 2017)
8	Number of official documents related to the proposed key projects	875	974	1488	2113	3118	(Scifinder, 2017)
9	Number of patents, research paper and conference topics of the proposed technology gaps	1440	1483	1789	1773	2084	(Scifinder, 2017)
10	Number of patent, research paper and conference topics of the proposed key technologies	1390	1628	1789	2118	2492	(Scifinder, 2017)

11	GDP growth (annual %)	10.636	9.536	7.856	7.758	7.298	(Worldbank, 2017a)
12	Labor cost (USD Million)	108.5	111.1	96.6	99.8	99.4	(Nbsc, 2016)
13	Number of proposed environmental problems and solutions searched	38	58	93	132	175	(Scopus, 2017)
14	Provision of raw materials mentioned (cotton million tons)	5.961	6.598	6.836	6.299	6.178	(Nbsc, 2017)
15	Household final consumption expenditure (% of GDP)	35.925	36.745	36.636	36.631	37.165	(Worldbank, 2017b)
16	Population growth (annual %)	0.483	0.479	0.487	0.494	0.506	(Worldbank, 2017c)
17	Number of proposed facilities and platforms searched	2	2	4	6	12	(Scopus, 2017)
18	Number of proposed polices and agreements searched	124	191	238	385	566	(Scopus, 2017)
19	R&D expenditures in the textile industry (USD Million)	3949.92	5146.67	6272.13	7380.37	8302.01	(Oecd, 2017a)
20	Number of dissertations in textile-related areas	4	10	10	4	0	(Scifinder, 2017)

4.3 Results

The external assessment results using normalized data, values of *C* (Change), and conformance results between original predictions and actual trends are presented in Tables 4.7 to 4.10. Following steps 2 and 3 of the measurement methods, the normalized data for actual statistics collected in Table 4.3 to Table 4.6 and the corresponding values of *C* are calculated, and the actual trend of each indicator is shown as well. The original predictions are searched and collected from the four ITRMs, with the evidence and key word. Following step 4 of the measurement methods, the conformance for each indicator is also investigated.

Table 4.7 External assessment results of the UK ITRM

	Indicator	Normalized data from 0 to 1					Value of C (Change)	Actual trend	Original prediction	Conformance (1=agree, 0=disgree)
		2007	2008	2009	2010	2011				
1	Value added (% of GDP)	1.00	0.75	0.00	0.11	0.23	-2.91	decrease	decrease	1
2	Exportation amount (USD Million)	1.00	0.79	0.00	0.32	0.94	-1.94	decrease	decrease	1
3	Importation amount (USD Million)	0.97	0.91	0.00	0.35	1.00	-1.62	decrease	decrease	1
4	Number of patents	0.80	0.00	1.00	0.20	0.80	-1.20	decrease	increase	0
5	Number of research papers	0.75	0.00	0.93	0.76	1.00	-0.31	decrease	increase	0
6	Number of conference topics	0.00	1.00	0.12	0.53	0.53	2.18	increase	increase	1
7	Number of official documents related to the proposed research areas	0.00	0.40	0.47	1.00	0.80	2.67	increase	increase	1
8	Number of official documents related to the proposed key projects	1.00	0.00	0.63	0.26	0.00	-3.11	decrease	increase	0
9	Number of patent, research paper and conference topics of the proposed technology gaps	0.27	0.00	0.82	0.91	1.00	1.64	increase	increase	1
10	Number of patent, research paper and conference topics of the proposed key technologies	1.00	0.27	0.00	0.38	0.30	-3.05	decrease	increase	0
11	GDP growth (annual %)	1.00	0.54	0.00	0.91	0.85	-1.71	decrease	decrease	1
12	Labor cost (USD Million)	1.00	0.70	0.00	0.04	0.15	-3.11	decrease	decrease	1
13	Number of proposed environmental problems and solutions searched	0.71	0.00	0.23	0.83	1.00	-0.80	decrease	increase	0
14	Provision of raw materials mentioned (cotton production in the US, 1000 bales)	1.00	0.09	0.00	0.84	0.48	-2.58	decrease	decrease	1
15	Household final consumption expenditure (% of GDP)	0.00	0.64	1.00	0.51	0.22	2.37	increase	increase	1
16	Population growth (annual %)	0.74	1.00	0.00	0.90	0.84	-0.23	decrease	decrease	1
17	Number of proposed facilities and platforms searched	0.00	0.11	0.50	0.65	1.00	2.26	increase	increase	1
18	Number of proposed polices and agreements searched	0.00	0.21	0.76	1.00	0.93	2.90	increase	increase	1
19	R&D expenditures in the textile industry	1.00	0.56	0.00	0.04	0.30	-3.09	decrease	increase	0

	(USD Million)									
20	Number of dissertations in textile-related areas	0.00	0.00	0.00	0.00	0.00	0.00	N/A	increase	0

Table 4.8 External assessment results of the Canadian ITRM

	Indicator	Normalized data					Value of C (Change)	Actual trend	Original prediction	Conformance (1=agree, 0=disgree)
		2007	2008	2009	2010	2011				
1	Value added (% of GDP)	1.00	0.00	0.30	0.48	0.37	-2.84	decrease	increase	0
2	Exportation amount (USD Million)	1.00	0.00	0.63	1.00	0.99	-1.35	decrease	decrease	1
3	Importation amount (USD Million)	0.48	0.00	0.47	1.00	0.98	0.51	increase	increase	1
4	Number of patents	0.00	1.00	0.50	0.63	0.50	2.63	increase	increase	1
5	Number of research papers	0.00	0.30	0.46	1.00	0.70	2.46	increase	increase	1
6	Number of conference topics	0.15	0.00	0.00	0.23	1.00	0.62	increase	increase	1
7	Number of official documents related to the proposed research areas	0.00	0.38	1.00	0.63	0.00	2.00	increase	increase	1
8	Number of official documents related to the proposed key projects	0.70	0.70	1.00	0.78	0.00	-0.30	decrease	increase	0
9	Number of patent, research paper and conference topics of the proposed technology gaps	1.00	0.00	0.82	0.07	0.36	-2.75	decrease	increase	0
10	Number of patent, research paper and conference topics of the proposed key technologies	1.00	0.97	0.65	0.97	0.00	-1.42	decrease	increase	0
11	GDP growth (annual %)	0.65	0.00	0.99	1.00	0.77	0.17	increase	increase	1
12	Labor cost (USD Million)	1.00	0.00	0.35	0.35	0.48	-2.82	decrease	increase	0
13	Number of proposed environmental problems and solutions searched	0.21	0.00	0.79	0.79	1.00	1.74	increase	increase	1
14	Provision of raw materials mentioned (textile raw material import, US dollar million)	0.67	0.00	0.85	0.85	1.00	0.03	increase	increase	1
15	Household final consumption expenditure (% of GDP)	0.00	1.00	0.81	0.46	0.51	2.78	increase	increase	1

16	Population growth (annual %)	0.49	0.82	0.66	0.00	1.00	0.52	increase	increase	1
17	Number of proposed facilities and platforms searched	0.27	0.00	1.00	0.87	0.87	1.67	increase	increase	1
18	Number of proposed polices and agreements searched	0.05	0.00	0.61	1.00	0.73	2.15	increase	increase	1
19	R&D expenditures in the textile industry (USD Million)	1.00	0.93	0.57	0.91	0.00	-1.59	decrease	increase	0
20	Number of dissertations in textile-related areas	0.00	0.67	0.00	1.00	0.00	1.67	increase	increase	1

Table 4.9 External assessment results of the US ITRM

	Indicator	Normalized data					Value of C (Change)	Actual trend	Original prediction	Conformance (1=agree, 0=disgree)
		2007	2008	2009	2010	2011				
1	Value added (% of GDP)	0.00	0.42	1.00	0.79	0.69	2.91	increase	increase	1
2	Exportation amount (USDD Million)	0.00	0.42	0.71	0.83	1.00	2.96	increase	increase	1
3	Importation amount (US Million)	0.00	0.49	0.64	0.78	1.00	2.90	increase	increase	1
4	Number of patents	0.95	1.00	0.68	0.00	0.23	-1.90	decrease	increase	0
5	Number of research papers	0.00	0.75	0.83	1.00	0.93	3.50	increase	increase	1
6	Number of conference topics	0.00	0.42	0.60	1.00	0.24	2.26	increase	increase	1
7	Number of official documents related to the proposed research areas	1.00	0.50	0.50	0.00	0.00	-3.00	decrease	increase	0
8	Number of official documents related to the proposed key projects	0.73	1.00	0.45	0.00	0.27	-1.21	decrease	increase	0
9	Number of patent, research paper and conference topics of the proposed technology gaps	1.00	1.00	1.00	1.00	0.00	-1.00	decrease	increase	0
10	Number of patent, research paper and conference topics of the proposed key technologies	1.00	0.76	0.63	0.41	0.00	-2.20	decrease	increase	0
11	GDP growth (annual %)	0.00	1.00	0.82	0.94	0.84	3.61	increase	increase	1
12	Labor cost (USD Million)	0.00	0.36	0.71	0.86	1.00	2.93	increase	increase	1
13	Number of proposed environmental problems and solutions searched	0.00	1.00	0.00	0.67	0.00	1.67	increase	increase	1

14	Provision of raw materials mentioned (Global synthetic fiber production, 1000 metric tons)	0.31	0.00	0.75	0.86	1.00	1.35	increase	decrease	0
15	Household final consumption expenditure (% of GDP)	0.28	0.13	1.00	0.41	0.00	0.44	increase	increase	1
16	Population growth (annual %)	1.00	0.71	0.19	0.18	0.00	-2.92	decrease	none	0
17	Number of proposed facilities and platforms searched	0.11	0.00	0.44	0.00	1.00	1.00	increase	increase	1
18	Number of proposed polices and agreements searched	0.00	0.92	0.50	1.00	0.67	3.08	increase	increase	1
19	R&D expenditures in the textile industry (USD Million)	0.00	0.30	1.00	0.64	1.14	3.07	increase	increase	1
20	Number of dissertations in textile-related areas	1.00	0.00	0.08	0.42	0.25	-3.25	decrease	increase	0

Table 4.10 External assessment results of the Chinese ITRM

	Indicator	Normalized data					Value of C (Change)	Actual trend	Original prediction	Conformance (1=agree, 0=disgree)
		2007	2008	2009	2010	2011				
1	Value added (% of GDP)	1.00	1.00	0.66	0.27	0.00	-2.06	decrease	decrease	1
2	Exportation amount (USD Million)	0.00	0.47	0.53	0.85	1.00	2.84	increase	increase	1
3	Importation amount (USD Million)	0.00	0.71	1.00	0.96	0.57	3.24	increase	increase	1
4	Number of patents	0.00	0.04	0.11	0.28	1.00	1.43	increase	increase	1
5	Number of research papers	0.00	1.00	0.33	0.94	0.70	2.98	increase	increase	1
6	Number of conference topics	0.00	0.46	0.10	0.41	1.00	1.97	increase	increase	1
7	Number of official documents related to the proposed research areas	0.00	0.15	0.42	0.63	1.00	2.20	increase	increase	1
8	Number of official documents related to the proposed key projects	0.00	0.04	0.27	0.55	1.00	1.87	increase	increase	1
9	Number of patent, research paper and conference topics of the proposed technology gaps	0.00	0.07	0.54	0.52	1.00	2.13	increase	increase	1
10	Number of patent, research paper and conference topics of the	0.00	0.22	0.36	0.66	1.00	2.24	increase	increase	1

	proposed key technologies									
11	GDP growth (annual %)	1.00	0.67	0.17	0.14	0.00	-3.02	decrease	decrease	1
12	Labor cost (USD Million)	0.82	1.00	0.00	0.22	0.19	-1.87	decrease	decrease	1
13	Number of proposed environmental problems and solutions searched	0.00	0.15	0.40	0.69	1.00	2.23	increase	increase	1
14	Provision of raw materials mentioned (cotton million tons)	0.00	0.73	1.00	0.39	0.25	2.36	increase	decrease	0
15	Household final consumption expenditure (% of GDP)	0.00	0.66	0.57	0.57	1.00	2.80	increase	increase	1
16	Population growth (annual %)	0.15	0.00	0.30	0.56	1.00	1.26	increase	increase	1
17	Number of proposed facilities and platforms searched	0.00	0.00	0.20	0.40	1.00	1.60	increase	increase	1
18	Number of proposed polices and agreements searched	0.00	0.15	0.26	0.59	1.00	2.00	increase	increase	1
19	R&D expenditures in the textile industry (USD Million)	0.00	0.27	0.53	0.79	1.00	2.60	increase	increase	1
20	Number of dissertations in textile-related areas	0.40	1.00	1.00	0.40	0.00	0.80	increase	increase	1

Fig. 4.3 shows that the Chinese ITRM received the best performance scores as 6 out of 7 attributes got 1 point as the predictions conformed to the actual trends. The value and supply chains were correctly predicted in the US ITRM, but it failed to make effective predictions for key technologies and industrial goals. For the Canadian ITRM, the predictions of the supply and innovation chains conformed to the actual trends, but the value chain and key technologies were not correctly predicted. The UK ITRM made effective predictions for value chain, supply chain, and macro environmental analysis.

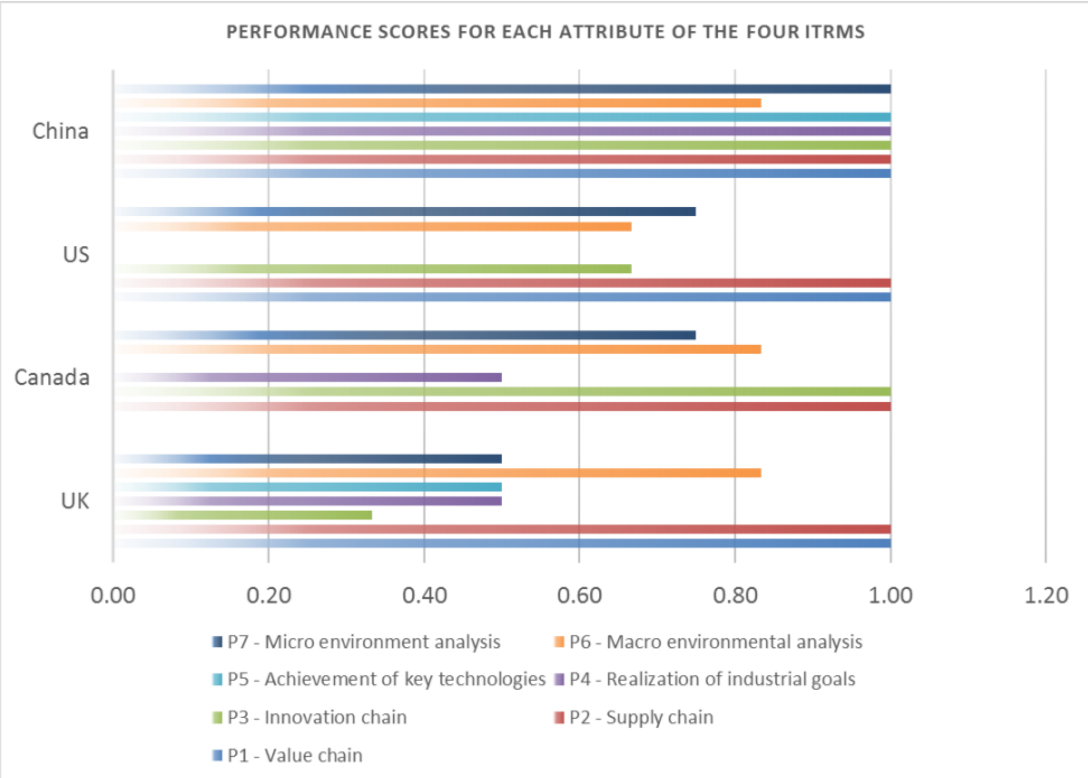


Fig. 4.3 Performance scores for each attribute of the four ITRMs

Fig. 4.4 indicates that the Chinese ITRM received the best scores for market and technology forces, and the deficiency between market and technology forces of the Canadian ITRM is the smallest among the four ITRMs. The Chinese

ITRM is the only one that showed higher performance scores of technology forces than market forces.

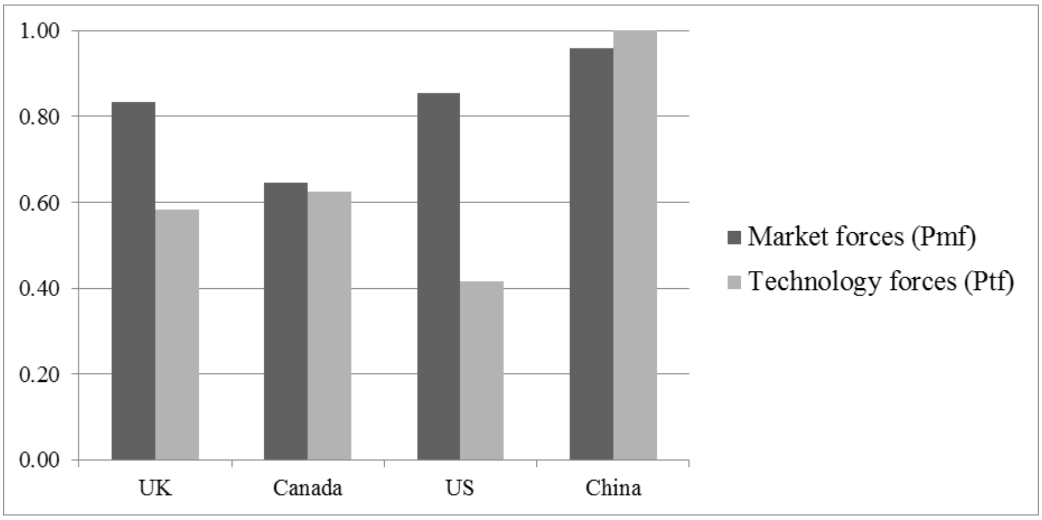


Fig. 4.4 Performance scores of market forces and technology forces in the four ITRMs

Fig. 4.5 shows that the increasing rank of the four ITRMs according to relative external deficiency is Canada and China, the UK, and the US.

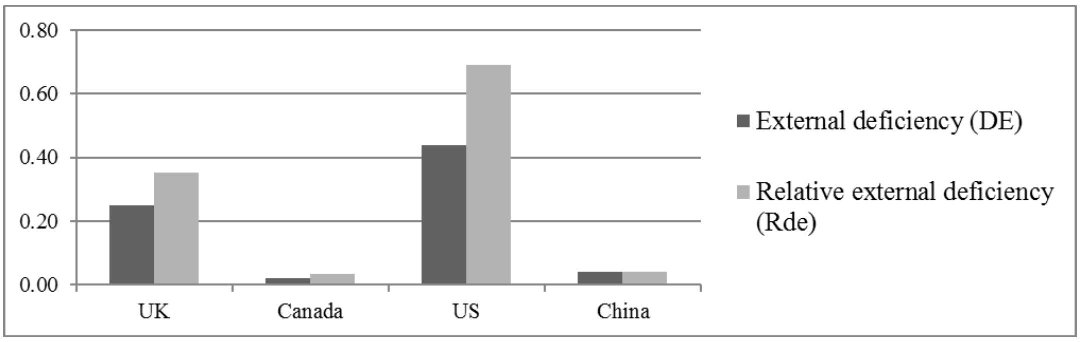


Fig. 4.5 Results of external deficiencies and relative external deficiencies of the four ITRMs

Fig. 4.6 shows a decreasing trend in the overall performance score and relative external deficiency among the Chinese, UK, and US ITRMs. The higher the ITRM performance score, the smaller the relative external deficiency between market and technology forces.

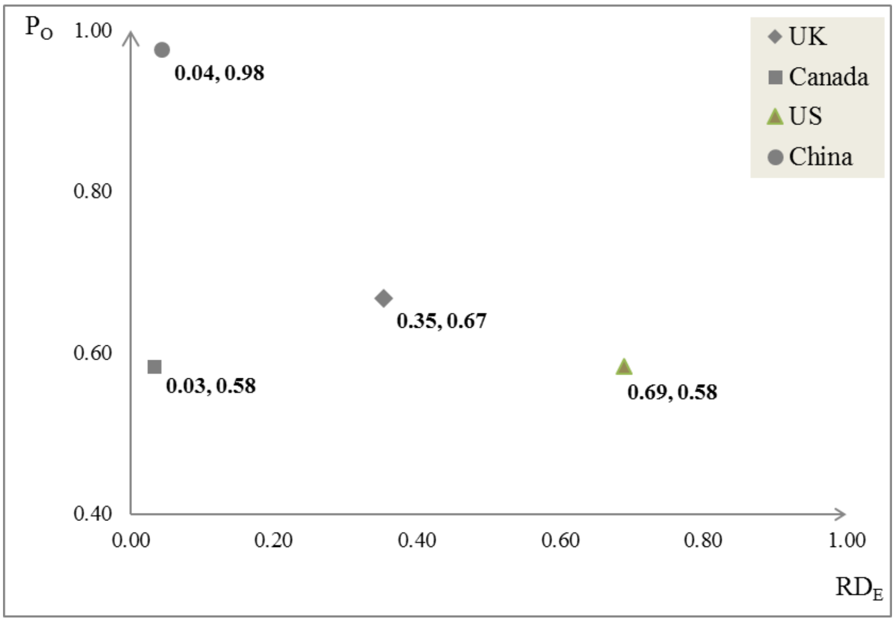


Fig. 4.6 Relationship among overall performances and external deficiencies of the four ITRMs

As shown in Table 4.11, the Chinese ITRMs have the highest overall performance score because it made correct predictions of 19 indicators out of 20. The UK ITRM ranked second and got an overall performance score of 0.67, with strength in market forces' prediction, such as value chain, supply chain, and macro environment. The Canadian and US ITRMs received the same overall performance score of 0.58, but their strength and weakness were different. The former one made poor predictions on value chain and achievement of key technology, but very good predictions on the supply chain, innovation chain, and macro environment, which resulted in similar scores between market forces and technology forces. On the contrary, big gaps existed between the two forces' performances in the US ITRM, and it did well in market forces prediction but worst in technology perspective.

Table 4.11 Overall results of performance measurement of the four ITRMs

ITRM	Origin	Overall performance score (P_O)	External deficiency (D_E)	Relative external deficiency (R_{DE})
Mapping of evidence on sustainable development impacts that occur in the life cycles of clothing (Madsen, 2007)	UK	0.67	0.25	0.35
Technology roadmap for Canadian textile industry (Cttgroup, 2008)	Canada	0.58	0.02	0.03
Industry technology roadmap for the flushable pre-moistened nonwoven wipes industry (Kim, 2009a)	US	0.58	0.44	0.69
Development of Technology Roadmap for Guangdong Textile and Clothing Industry (Li & Xiong, 2010a)	China	0.98	0.04	0.04

4.4 Discussion

Except for the Chinese ITRM, the three ITRMs exhibited good performance of market-force-related attributes (Fig. 4.4). The original predictions relating to technology forces in ITRMs were relatively weak. When relative external deficiency is considered, three ITRMs out of four had deficiencies between market and technology forces (Fig. 4.5). In addition, overall performance scores and deficiencies should complement each other. For example, the Canadian and US ITRMs had the same overall performance score of 0.58, but had extremely different results on deficiencies; the Canadian and Chinese ITRMs had close results on deficiencies, but their overall performance scores of 0.58 and 0.98, respectively, had a large difference. Fig. 4.6 showed a decreasing trend between the results of overall performance (P_O) and relative external deficiency (R_{DE}). The smaller deficiency that the performances of the market forces and technology forces have, the better is the overall performance of an ITRM. More cases in different industries within different periods are still needed to investigate the tendency. The academic resources also had good impact on the actual performance of an ITRM, as seen in the Chinese and UK roadmaps. The Chinese ITRM ranked first for overall performance and invited professionals from the academe to participate in roadmapping activities, such as surveys, workshops, and symposia. The UK ITRM, ranked second, and used many second-hand academic documents for references to present the status of market and technology forces, as well as make decisions on future predictions and industrial plans.

4.5 Recommendations

Based on the theoretical framework and calculation results, the following success factors are recommended to guide the roadmapping process, particularly for the textile industry. With this experience, more case studies in other industries can be performed and assessed to widen the applications of the proposed external assessment model.

(1) Improve the effectiveness of technology forces

To connect market demands and technology innovation, and minimize their gaps, the accuracy and effectiveness of technology forces in an ITRM is key. In the preparation stage, qualified expert panels and research team should be formed, and the methodology should be clearly identified. In the roadmapping stage, critical analysis of current and potential market demands as well as technology development status is highly recommended, so that the goals and technology can be mapped in the appropriate routine.

(2) Attach balanced importance to market and technology forces

Different readers may have different needs and expectations in an ITRM. Unlike technology roadmap for corporates, it is not advisable that an ITRM only focuses on some perspectives to satisfy a specific group of readers, since the main task of an ITRM is to better match market demands and technology development. Only in-depth understanding and reasonable prediction of all relevant attributes in both perspectives can produce a successful ITRM. Therefore, it is recommended to attach balanced importance to market and technology forces.

(3) Multi-organizational background

Experts from different geographical and professional backgrounds can have different strengths and contributions to a roadmap. Inviting renowned experts in academia, industry, and governmental department worldwide to establish expert panels is recommended. Methods such as expert forums, workshops, interviews, and questionnaires are also recommended to generate ideas from the experts.

4.6 Conclusion

To systematically assess an ITRM, internal assessment on content quality and external assessment on actual performance are two main components. The concept and measurement of overall performance and external deficiency, and complementary parts to content quality and internal deficiency, may significantly contribute to the quantitative assessment of roadmaps.

The essence of the external assessment model is the measurement of actual performances of the target industry connecting original contents of an ITRM. To maximize the effectiveness and accuracy of an ITRM, the creation methods and processes of the ITRM should be kept active and improved by actual performance assessment dated back to the publication time. The findings of this chapter can help practitioners to develop an effective ITRM with awareness of the effectiveness and accuracy of actual industrial development, complementary to guidelines and knowledge framework in the previous chapter.

Chapter 5 Relationship between Internal Quality and External Performance

The internal assessment model for content quality and the external assessment model for actual performance are proposed and applied to assess four global ITRMs in Chapters 3 and 4, respectively. Through the external model, actual data for different indicators were collected from published databases and used to validate the experts' rating in the internal model. In this chapter, the relationship between internal content quality and external actual performance is investigated for further validation of the assessment models proposed in Chapter 3 and 4.

That a relationship exists between internal quality and external performance is hypothesized. To test the hypothesis, the correlations between internal quality and external performance of the four global textile ITRMs are examined using a path diagram (Fig. 5.1). Using the results as basis, the success factors for an ITRM are summarized. To provide effective guidelines for future ITRM assessment, flowcharts for internal and external assessments are provided in this chapter.

5.1 Relationship Investigation

Fig. 5.1 shows the path diagram for correlations between all the key attributes and overall measures of internal quality and external performance of an ITRM.

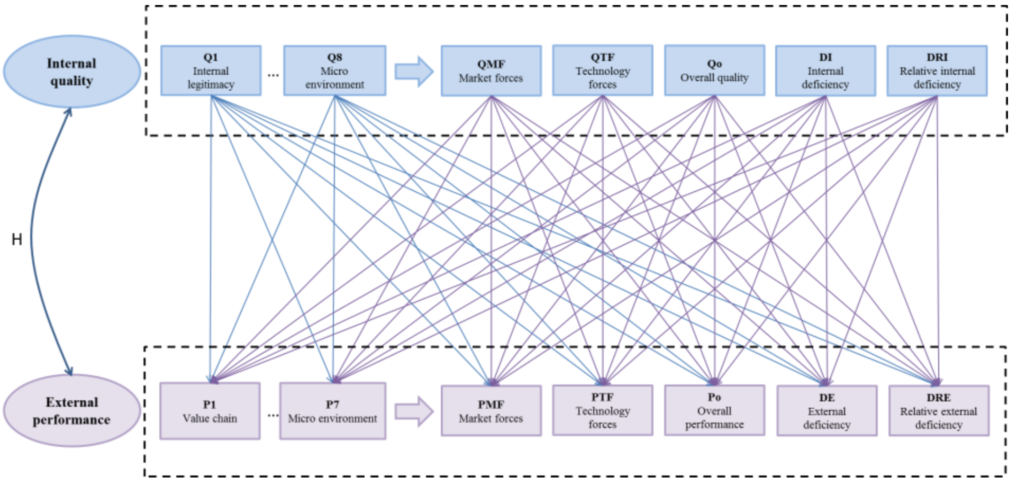


Fig. 5.1 Path diagram for correlation analysis

The internal quality of the four textile ITRMs includes eight key attributes (Q_1-Q_8), calculated market force quality (Q_{MF}), technology force quality (Q_{TF}), overall internal quality (Q_O), internal deficiency (D_I), and relative internal deficiency (D_{RI}). The corresponding external performances comprise seven key attributes (P_1-P_7), calculated market force performance (P_{MF}), technology force performance (P_{TF}), overall external performance (P_O), external deficiency (D_E), and relative external deficiency (D_{RE}). These two sets of variables are correlated using SPSS Statistics version 20.

5.2 Results

The results show statistically significant linear relationships between several variables of internal quality and external performance. The meaningful relationships between the quality of key attributes and technology forces and overall quality are discussed in the following subsections.

5.2.1 Relationship between the quality of industrial goals and overall performance

Among the eight key attributes, the quality score of industrial goals (Q_5)

correlates with the overall performance (P_O) at a 0.01 significant level as shown in Fig. 5.2.

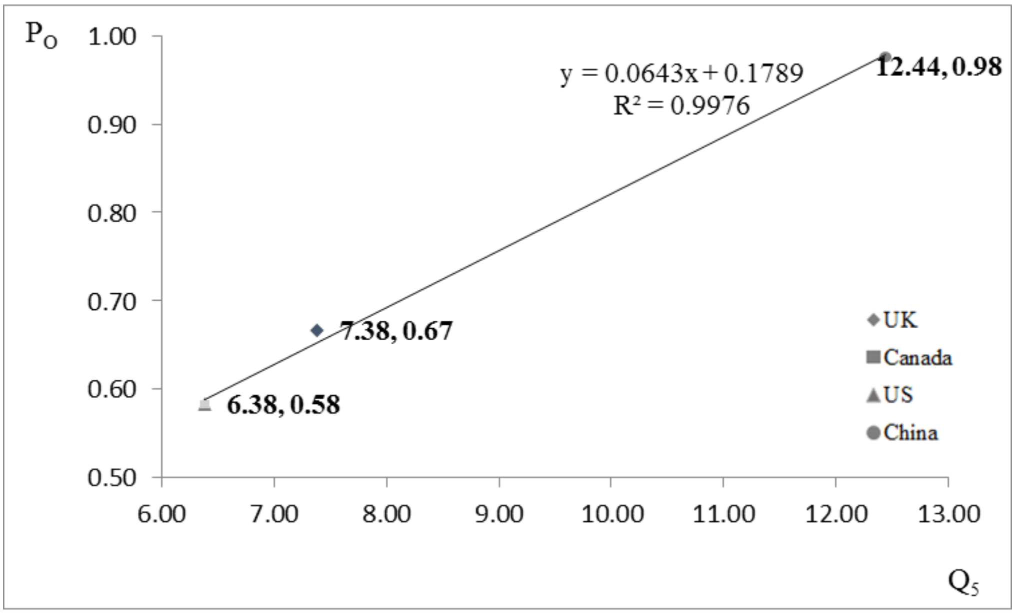


Fig. 5.2 Relationship between Q_5 and P_O

Figure 5.2 shows a strong positive linear correlation between the quality of industrial goals and the overall performance of the ITRMs. The value of the coefficient of determination R^2 is 0.9976, that is, 99.76% of the total variation in P_O. Better content quality of industrial goals translates to better actual performance, which indicates that an ITRM can give better guidance for the industry development if its industrial goals have been well identified. Developing the qualified contents of industrial goals requires success in various aspects, such as updated knowledge of the current status and potential demands of markets as well as the current, required, and possible development of technology and innovation. High-quality industrial goals cannot be developed without appropriate methods, renowned expert panels, qualified research team, and reliable data sources.

5.2.2 Effects of the quality of technology forces

5.2.2.1 Relationship between quality of technology forces and performance

Fig.5.3 shows that the value of the coefficient of determination R^2 is 0.7556 and reveals a positive correlation between the performance scores of technology forces (P_{TF}) and corresponding content quality scores (Q_{TF}) of the four ITRMs. Better content quality of technological forces results in better performance of technology forces. The result indicates that an ITRM with high-quality contents of technology-force-related attributes, including supply chain, innovation chain, industrial goals and key technology, can provide better guidance to the future technology development for the industry.

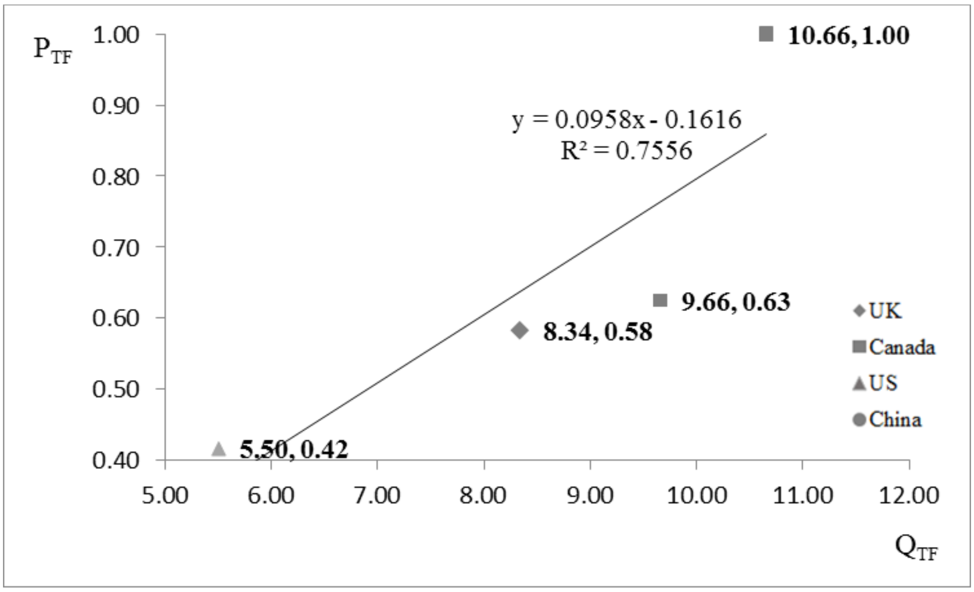


Fig. 5.3 Relationship between Q_{TF} and P_{TF}

5.2.2.1 Relationship between quality of technology forces and external deficiency

Figs. 5.4 and 5.5 show that the quality score of technology forces (Q_{TF}) correlates to the external deficiency (D_E) and the relative external deficiency

(D_{RE}) at 0.05 significance level.

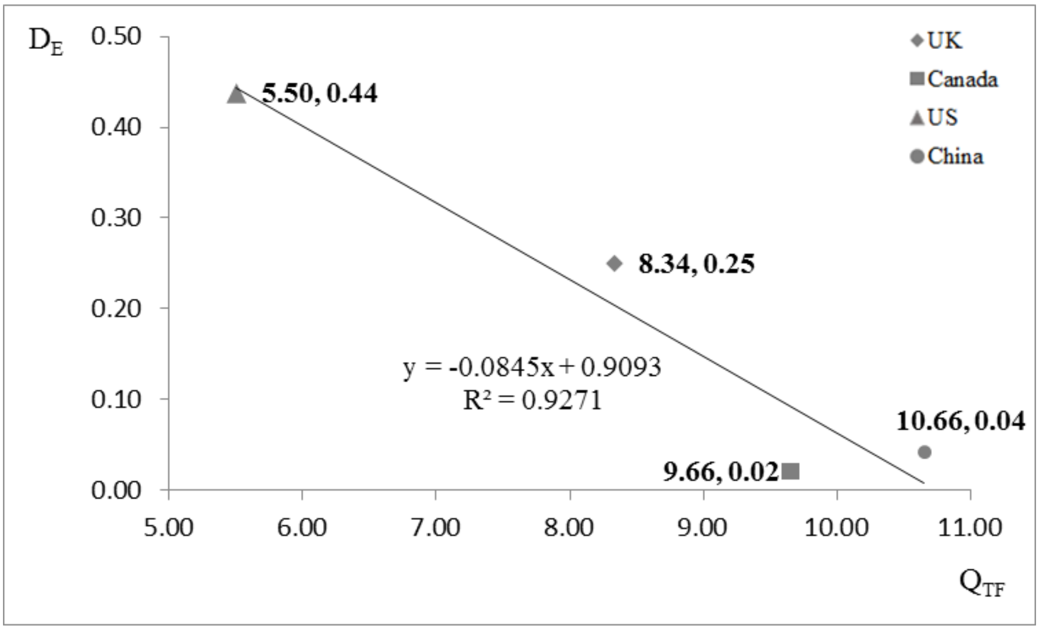


Fig. 5.4 Relationship between Q_{TF} and D_E

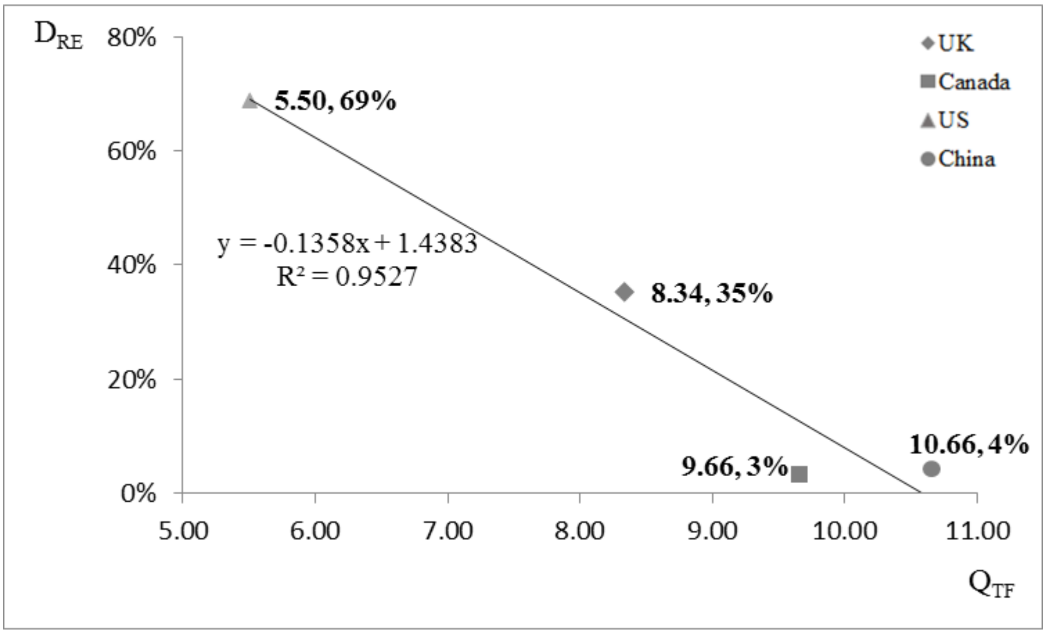


Fig. 5.5 Relationship between Q_{TF} and D_{RE}

Figs. 5.4 and 5.5 show that the quality of technology forces (Q_{TF}) exhibits strong negative linear correlations with external deficiency (D_E) and relative external deficiency (D_{RE}), because the values of coefficient of determination R^2 are over 0.92. This finding reveals that the content quality of technology forces plays an important role in the deficiency of performances between market and technology forces. Considering the trend in Fig. 5.3, an ITRM with high-content-quality technology forces can achieve good performance in technology forces and lessen external deficiency.

5.2.3 Relationship between overall quality and external deficiency

Fig. 5.6 shows the relationship between the overall quality and external deficiencies of the four textile ITRMs, and Fig. 5.7 shows the relationship between overall quality and relative external deficiencies.

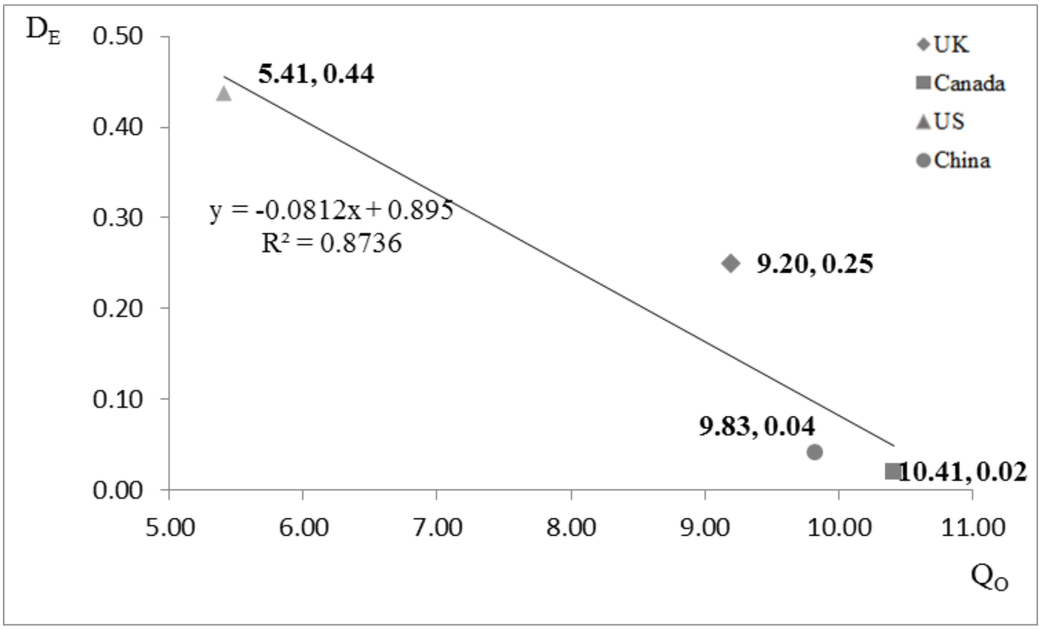


Fig. 5.6 Relationship between Q_O and D_E

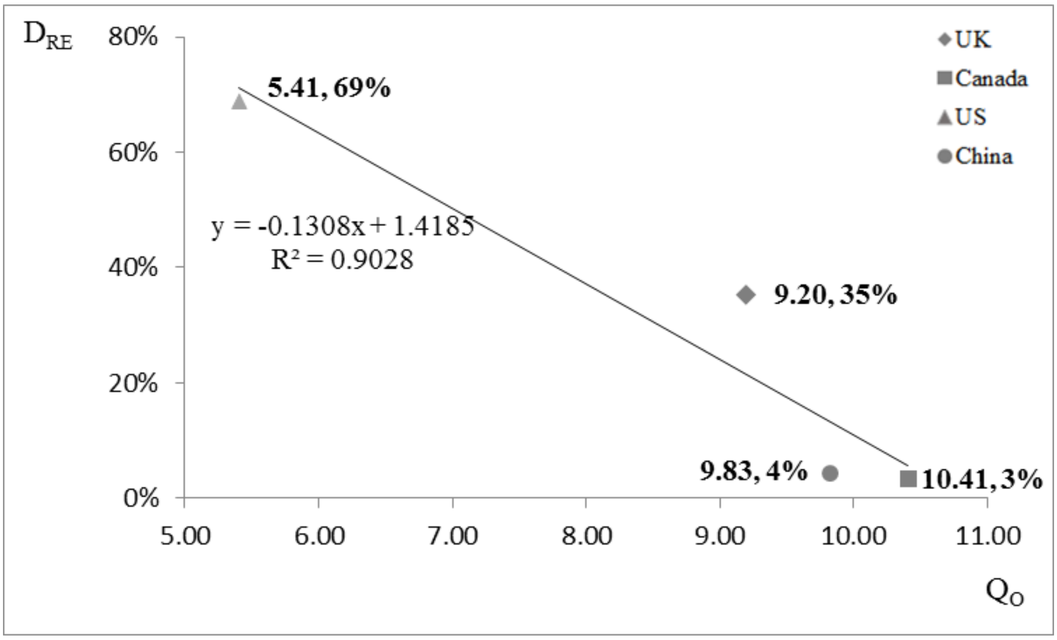


Fig. 5.7 Relationship between Q_O and D_{RE}

Figs. 5.6 and 5.7 demonstrate that both external deficiencies and relative external deficiencies have strong negative linear correlations with overall quality. An ITRM with better content quality has smaller relative deficiency of performances between market and technology forces. These two figures indicate that an ITRM can give more balanced guidance for both market and technology development of the industry, if the roadmap's overall contents have been well developed.

5.2.4 Discussion

Using the data of the four global textile ITRMs, the results of correlation analysis supports the hypothesis. Correlations exist between Q_5 and P_O, Q_{TF} and P_{TF}, Q_{TF} and D_E, Q_{TF} and D_{RE}, Q_O and D_E, and Q_O and D_{RE}. The results imply that the internal quality and external performance of an ITRM are interrelated, and both internal and external assessment models are applicable. Studying cases in different industries is recommended to verify the relationship between the internal quality and external performance of an ITRM.

5.3 Success Factors for ITRM

On the basis of the findings of Chapters 3 to 5, Fig. 5.8 summarizes the success factors for ITRM, especially for the textile industry, as recommendations for future practitioners.

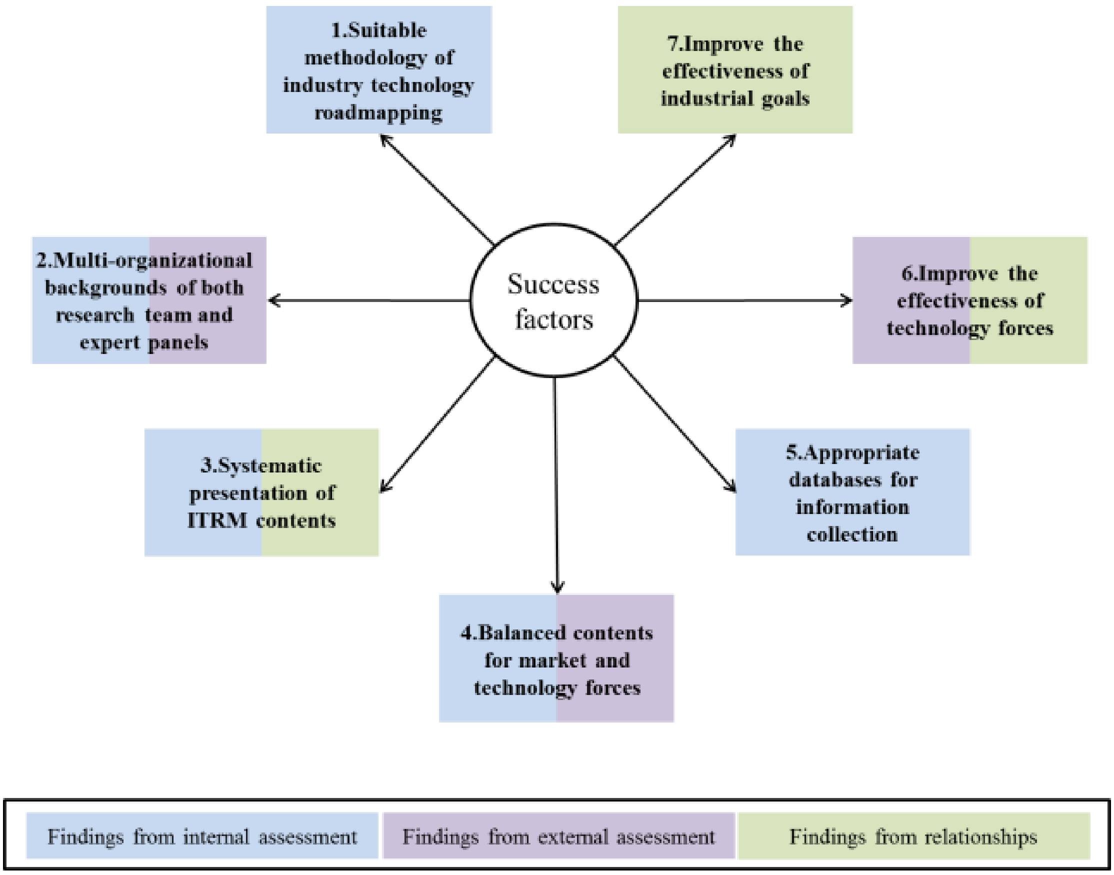


Fig. 5.8 Summarized success factors for ITRM

5.4 Guidelines for ITRM Assessment

The newly proposed internal and external assessment models are confirmed applicable for ITRM assessment in Chapters 3 to 5. For future applications, the process flowcharts for internal and external assessments are plotted in Figs. 5.9 and 5.10.

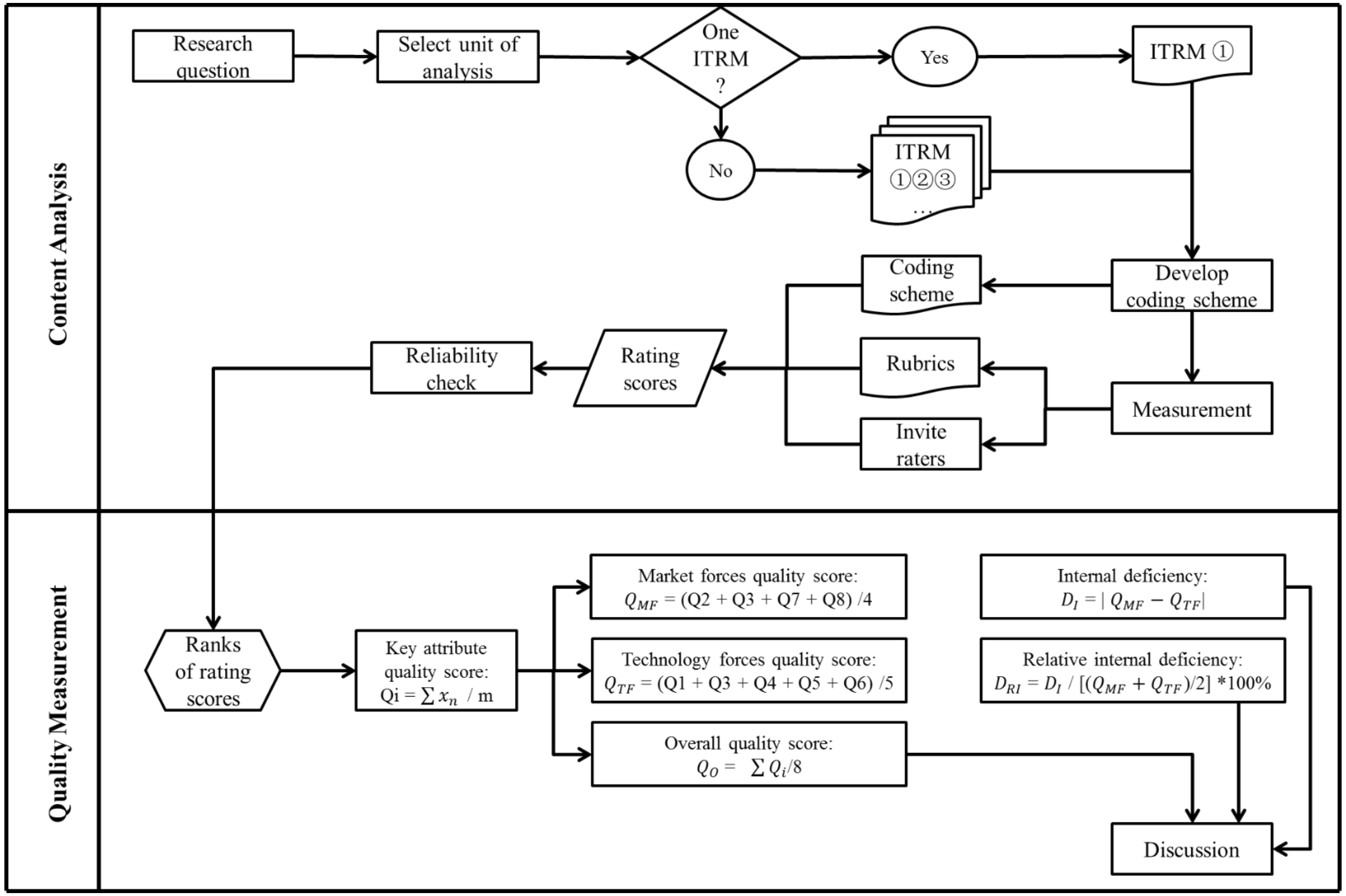


Fig. 5.9 Flowchart for internal quality assessment of ITRMs

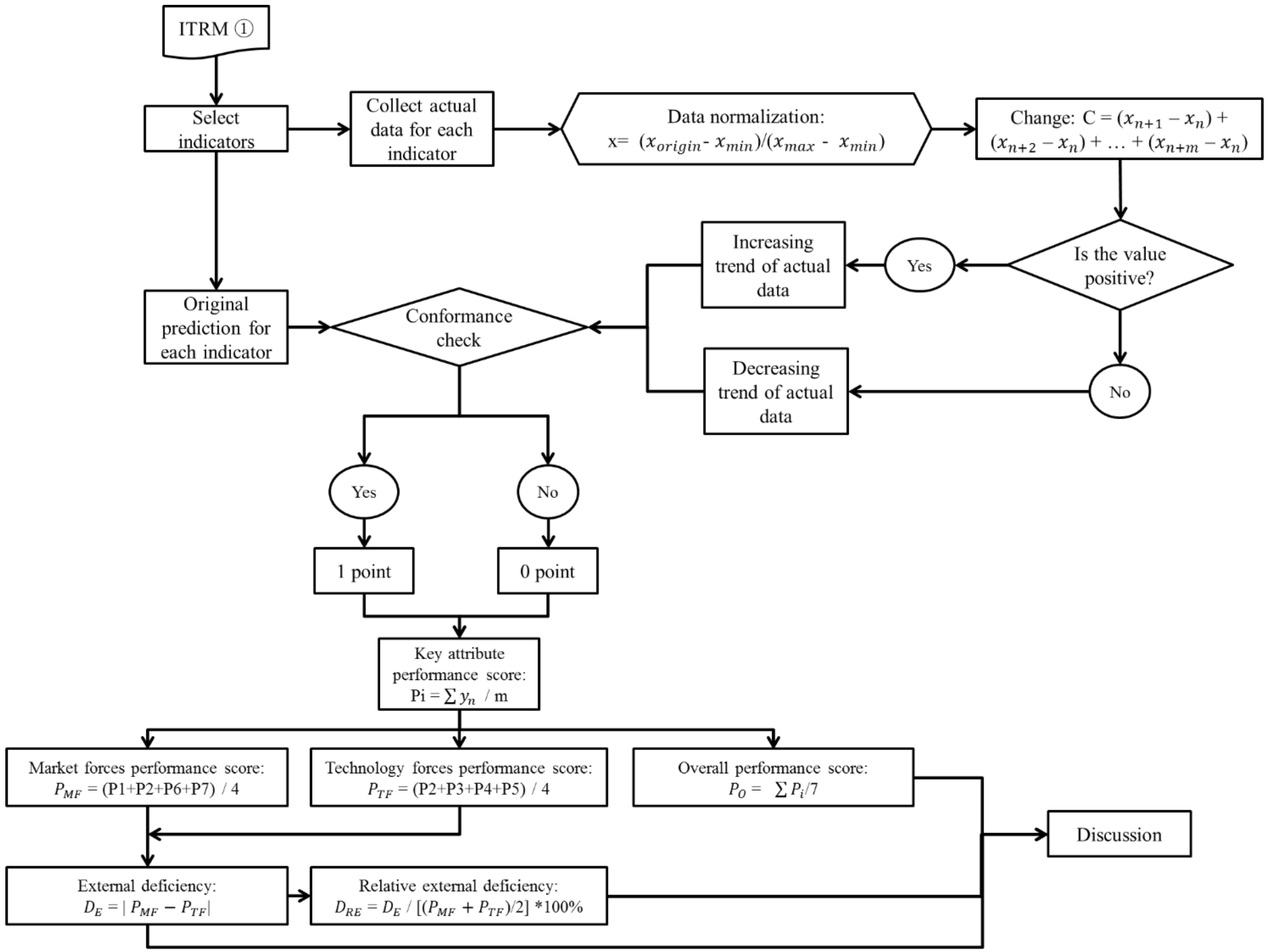


Fig. 5.10 Flowchart for external performance assessment of ITRMs

Fig. 5.9 shows that internal quality assessment includes two main stages—content analysis and quality measurement. In the first stage, the research question relating to internal quality is proposed, and the unit of analysis is selected (the ITRM for assessment). If only one ITRM will be assessed, then, it is the unit of analysis. If more than one ITRM will be assessed, then the ITRMs will have different units of analysis. According to the units of analysis determined, the coding scheme is developed, and rubrics and rater invitations are prepared for measurement. With the coding scheme and rubrics, invited raters score all the ITRMs. The following step is to check the reliability of the collected scores. If the reliability of scores is acceptable, then the second stage—quality measurement—can be conducted. The collected rating scores are transferred to ranks, and the quality score of each key attribute (Q_i) is calculated. Using the provided formulas, the quality scores of market forces (Q_{MF}) and technology forces (Q_{TF}) are calculated for internal deficiency (D_I) and relative internal deficiency (D_{RI}). The overall quality score is also calculated. With all these results, the internal quality of the investigated ITRM is discussed.

Fig. 5.10 illustrates the processes of external performance assessment of ITRMs. Based on the investigated ITRM, the first step is to select the assessment indicators using the rule of data availability. The second step is to collect original prediction for each indicator. The third step is to collect actual data for each indicator from relevant databases. Using the collected data, the normalized result of the data in different units (x) and change (C) are derived to judge the changing trends of actual data in the investigated period. The fourth step is to check the conformance between original prediction and actual data, and 1 or 0 is given to each key attribute as performance scores (P_i). Using the provided formulas, performance scores of market forces (P_{MF}) and technology forces (P_{TF}) are calculated for external deficiency (D_E) and relative external deficiency (D_{RE}). The overall performance score is also calculated. With all these results, the external performance of the investigated ITRM is discussed.

5.5 Conclusion

The relationship investigation of the four textile ITRMs indicates that the internal content quality correlates with the prediction accuracy of external performances. The validation in this chapter and the actual data calculation in Chapter 4 provide evidences to prove that the internal model is appropriate and scientific for ITRM's content quality assessment. Therefore, the internal assessment model can be also used as the guidelines for content development of an effective ITRM; while the external assessment model can be used for both rolling revision and effectiveness check. The success factors of ITRM, especially for the textile industry, and the detailed guidelines for ITRM assessment have also been summarized for future practitioners.

Chapter 6 Development of the Advanced Textile ITRM in the UK

The internal and external assessment models were proposed, along with the theoretical framework, assessment methods, and measurements of content quality and actual performance in Chapters 3 and 4, respectively. To verify the feasibility of the two models, four ITRMs in the textile industry were assessed as case studies, and relevant success factors were recommended. Based on the results, Chapter 5 establishes the relationship between internal quality and external performance of an ITRM.

In this chapter, the ongoing development of the UK advanced textile ITRM is assessed also on the basis of the newly developed internal assessment model to predict its content quality. Suggestions for necessary improvements, an integrated ITRM for the UK textiles and an individual ITRM for the biomedical textile sector are developed by the author as a member of this UK roadmap research team.

6.1 Development Process of Advanced Textile ITRM in the UK

6.1.1 Background

The textile industry in the UK is under a period of resource reallocation and technology upgrade for revival. Alliance Project, a non-profit organization based on New Economy was established to support the repatriation of textile manufacture in the UK. The following five reports were published on the current industrial status.

- Repatriation of the Textile Industry to the UK (Allianceproject, 2014)

- The Revival of the UK Textiles Industry (Allianceproject, 2015a)
- Research and Development and Innovation in UK Textiles (Allianceproject, 2015b)
- Toward a strategy for UK textiles innovation (Allianceproject, 2015c)
- Coming Back? Capability & Precarity in UK Textiles & Apparel (Froud et al., 2017)

To inject new energy to this traditional industry, a strategic plan was needed to re-allocate and re-integrate existing resources.

Commissioned by Lord David Alliance and the Greater Manchester Combined Authority with the support of Government through BIS (Economy, 2015), the Alliance Project team invited academic experts in textile science and engineering from the School of Materials in the University of Manchester to develop an ITRM for the advanced textile industry.

In the preliminary period, the Alliance Project team conducted surveys and individual case studies on UK textile firms. A research team, including academic experts from the University of Manchester as well as the team members of the Alliance Project, was established for the roadmapping. The development process is discussed in the following subsection.

6.1.2 Development process

Fig. 6.1 illustrates the flowchart of the development processes of the UK advanced textile ITRM. The flowchart depicts a scenario of strategic planning and roadmapping for the development of the UK advanced textile industry, with the aim of minimizing the deficiency between future market demands and technology innovation development.

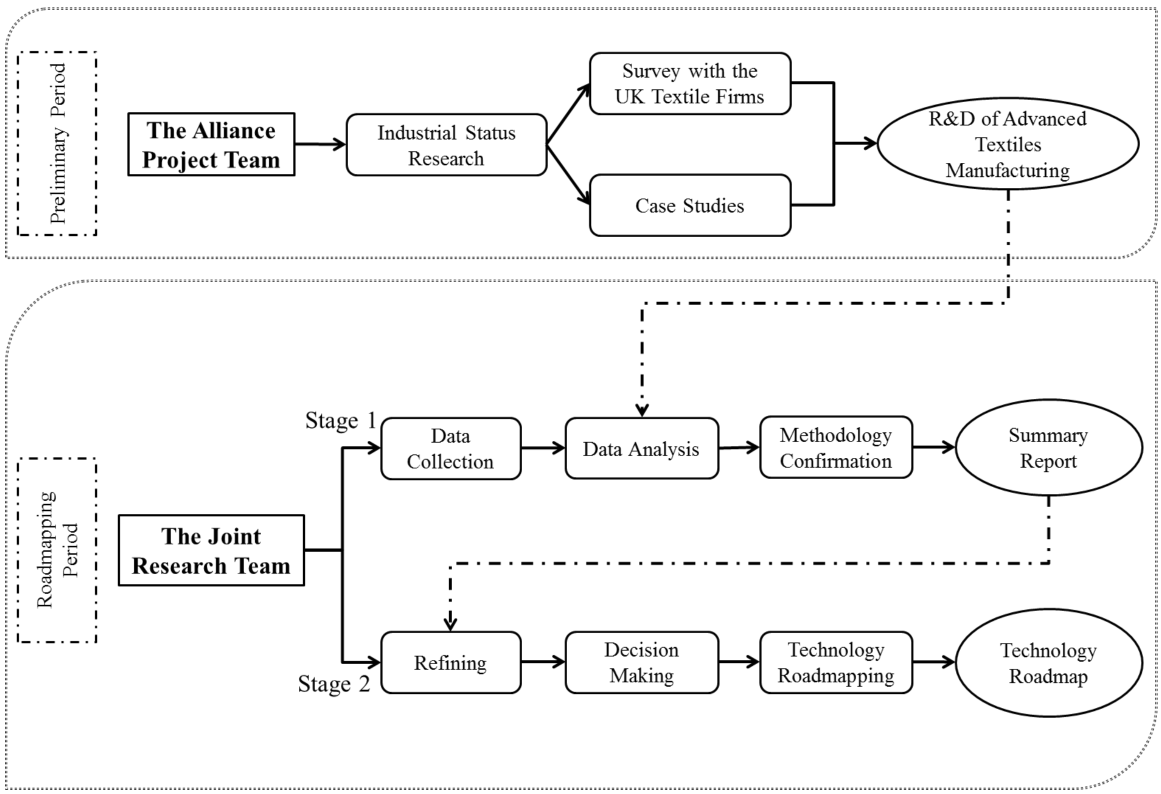


Fig. 6.1 Flowchart of the development process of the UK advanced textile ITRM

The development consists of two main periods—preliminary period by the Alliance Project team and roadmapping period by the joint research team of the Alliance Project and University of Manchester.

In the preliminary period, the Alliance Project team conducted an industrial status research on the advanced textile manufacturing in the UK. A database of more than two thousand companies in the advanced textile sector from different areas in the UK was established. Ninety-four textile-related companies was formed an industrial founded panel. Industrial experts, such as R&D directors and managers of the founded panel, were invited to participate in a survey and provide professional ideas from the views of market and industry development. Moreover, several case studies on local textile brands were conducted (Allianceproject, 2014),so as to address the existing problems (Allianceproject, 2015a). Based on these activities, a report about the R&D of the textile manufacturing was drafted (Allianceproject, 2015b).

With the collected data and summarized report, a joint research team of the Alliance Project and University of Manchester was formed to develop an ITRM for the UK advanced textile industry. The roadmapping period included two stages. In the first stage, industrial status was analyzed based on the drafted report produced in the preliminary period as well as the secondary data collected from the existing literature. The methodology of technology roadmapping was confirmed by the joint research team. A summary report of the status of the UK advanced textile industry was produced.

In the second stage, the newly-produced report was refined by the academic expert panel formed in the School of Materials of the University of Manchester. Discussions and small-scale forums were organized for decision making and technology roadmapping by the expert panel. An ITRM was developed for the UK advanced textile industry by the joint research team.

6.2 Internal Assessment of the UK Advanced Textile ITRM

During a visit to the University of Manchester and participation in the roadmapping team for four months, the newly-developed internal assessment model was applied to assess the quality of the existing contents and new contents were developed for the attribute yet accomplished. The results were published in a paper “Current status of the UK textile industry and its sustainable development” (Li et al., 2016). First-hand data analysis of the UK textile industry was used to supplement the existing reports by the Alliance Project team to recommend a methodology for roadmapping and develop an ITRM for the UK advanced textile industry.

The assessment and development process of the UK advanced textile ITRM was recorded against the eight key attributes depicted in Figure 3.1, including internal legitimacy, value chain, supply and innovation chains, industrial goals, key technology, and macro and micro environment.

6.2.1 Internal legitimacy

6.2.1.1 Methodology

Technology roadmaps created a full image of near future development with clear key areas, important breakthrough projects, and resource flow. This image would be an effective and scientific method for industrial medium- or long-term targets, especially for those in the survival and leaping stages (Li et al., 2016). Based on previous studies (Li et al., 2013b; Li et al., 2010d), industry technology roadmapping was adopted. To make decisions for the roadmapping, industrial surveys, case study, expert forums, and integrated analysis were conducted with the use of the Delphi method, brainstorming, SWOT analysis, and radar and bar charts (Li et al., 2016).

6.2.1.2 Expert panel

Managing and R&D directors in the 94 British founded companies for the Alliance Project were invited as the industrial expert panel. Academic professors and staff from the School of Materials in the University of Manchester were invited as the academic expert panel.

6.2.1.3 Research team

During the period when the author was a member of the joint research team for the technology roadmapping process established by the Alliance Project team and a group of academic experts from the School of Materials in the University of Manchester from August to December in 2015, the attributes of ITRM were assessed using the internal assessment model.

6.2.2 Industry value chain

Using keywords such as "value," "price," and "cost," a content review of the five reports listed in Section 6.1.1 was conducted. A table of alignment of conditions for sustainable cost recovery listed the positive capabilities of productive and marketing sets, with limited exposure to price-based competition and/or secured low cost producer status and higher prices, respectively. The negative capabilities were higher prices with weak margins and low end precarity with price competition (Froud et al., 2017, p. 24). The UK sector cannot compete only on price due to the high manufacturing cost. Manufacturers have, therefore, differentiated their products by competing on “delivery times, nearness to market and flexible production systems” (Froud et al., 2017, p. 54).

However, the value chain of the UK advanced textile industry had yet to be well studied. A survey was suggested to collect the costs and profits of different firms within different sectors in the UK, such as raw materials, textile processing, dying and functional treatment, design, garment or final product manufacturing, and marketing and sales. With the Alliance Project’s database of more than two thousand firms, the added value of each sector and integrated value chain status of the industry could be revealed with actual statistical support.

6.2.3 Industry supply chain

The general status of the supply chain for the UK advanced textile industry and many cases had been well presented. An industrial district was proposed for the firms that are always embedded in certain kinds of environment through multiple links. Co-location in firm clusters may be a striking exception. However, given the limits on vertical integration, most firms are embedded in local or global supply chains which link the providers of goods and services—from raw to processed materials and finished goods—from upstream to downstream customers (Froud et al., 2017, p. 25).

The author conducted an analysis on the geographical distribution of UK advanced textile firms in the abovementioned database of more than 2000 firms because the contents of the five reports of industry value/supply chain were descriptive and very general. The analysis was done as a part of the Alliance Project (shown in Figs. 6.2 and 6.3). Fig. 6.2 shows that in terms of geographical distribution, Great Manchester, Leicestershire, and West Yorkshire were the top three areas with most companies in advanced textiles in the UK. Fig. 6.3 shows that the UK advanced textile companies concentrated upon materials—non-woven and converting as well as materials—coating and laminating, bonding, print, dye, and finish.

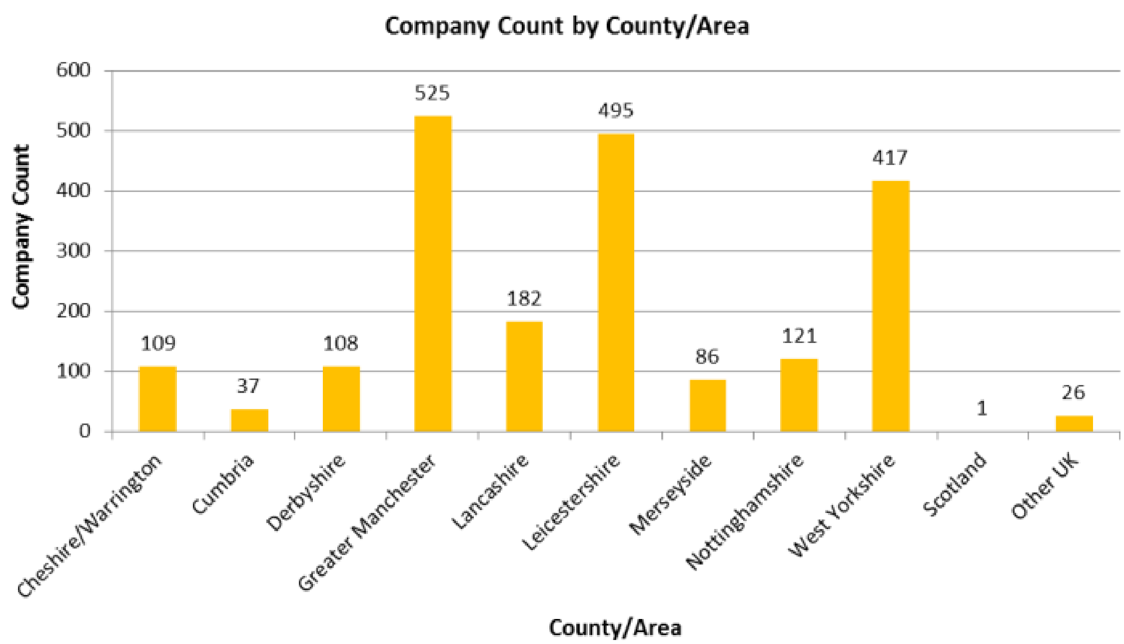


Fig. 6.2 Geographical distribution of UK advanced textile firms

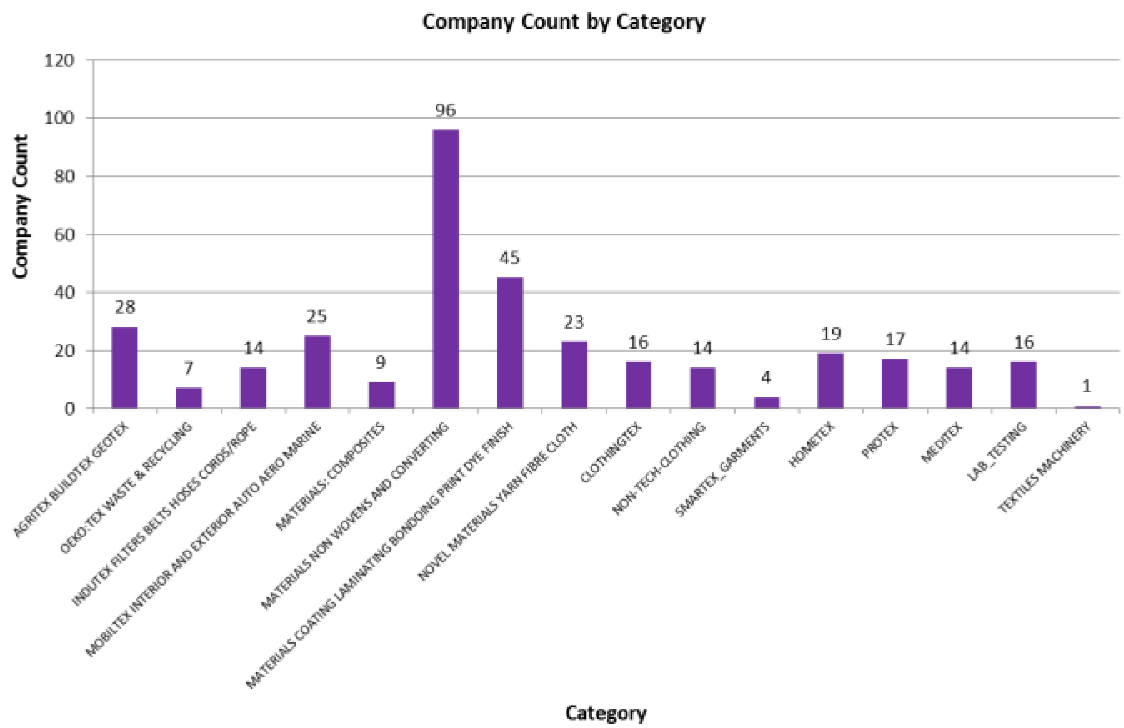


Fig. 6.3 Category distribution of UK advanced textile firms

6.2.4 Industry innovation chain

The innovation chain had not been well analyzed in the five reports by the Alliance Project team. Based on filed patents and SCI index paper publication, the author analyzed the global and UK domestic textile innovation chain. Through SCIFinder, the joint research team selected Textile and/or Clothing as keywords to search for relevant patents in English from 2000 to 2015. Fig. 6.4 illustrates that the US, the UK, and Italy are the top three countries possessing the largest number of patents published in English in these 15 years. A total of 1366 US, 160 British, and 135 Italian patents were identified. However, data did not include patents in other languages, such as Japanese. A growing number of patents published in Chinese were also found because the innovation strength of the Chinese textile industry had been increasing due to its domestic industrial upgrade and good performance in textile innovation.

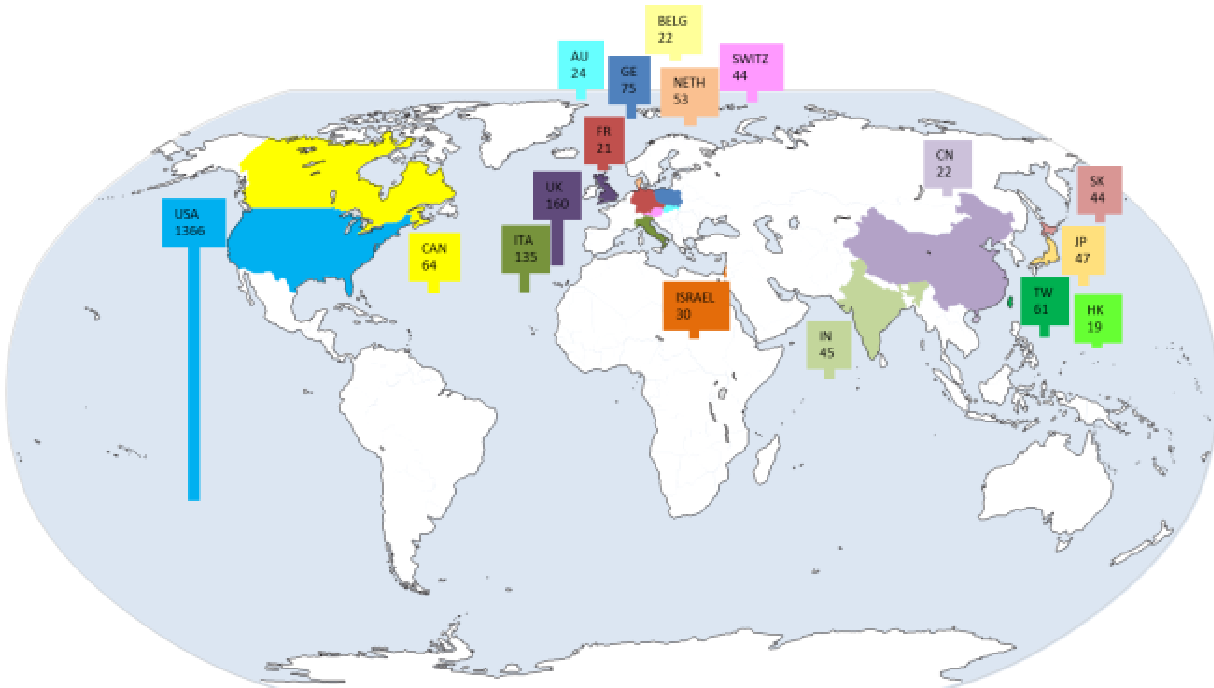


Fig. 6.4 Geographical distribution of searched patents in English (2000–2015)

Fig. 6.5 presents the number of textile and clothing patents in the UK by year, which provides a picture of the industrial performance in the textile innovation chain. In terms of filed patent, 2002–2011 were prosperous ten years for technology and innovation development in the UK textile industry. The number sharply decreased from 2011 to 2015, which was the boom of technical textile in the whole world. The UK textile industry missed the chance to be one of the top countries for technical textiles. Such case was due to its traditional development pattern and overwhelming reliance on micro-scale or family firms. Upgrading its core competitiveness and developing novel products should be the nation's main concerns.

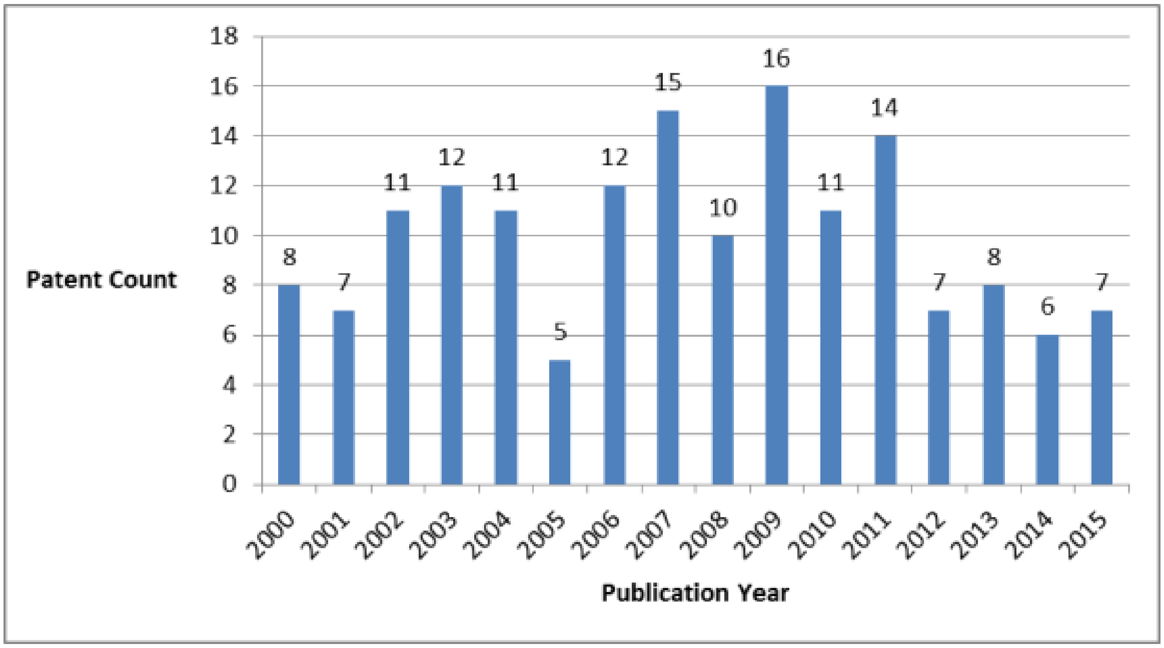


Fig. 6.5 Patent count by publication year in the UK

Fig. 6.6 shows that Unilever Plc, holding 52 patents, is listed at the top followed by P2i Ltd. and the Secretary of State for Defense. Obviously, the Unilever Group was playing a dominant position in textile innovation in the UK.

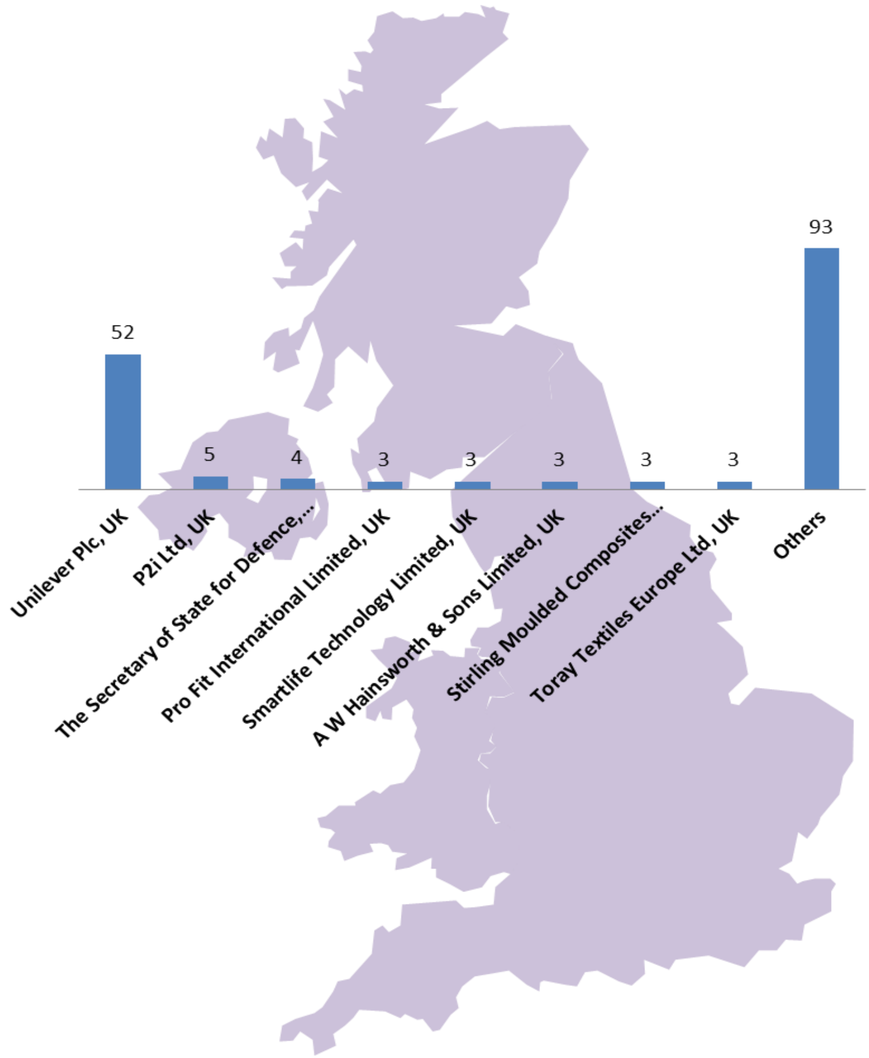


Fig. 6.6 Patent count by organization in the UK

By searching from the Web of Science, the countries of origin of the SCI indexed papers with keywords, namely, Textile and/or Clothing from 2000 to 2015 are presented in Fig. 6.7. Academia in the US published 7478 papers and is ranked the top of the world, followed by those in China with 6930 papers. The UK, Germany, and India are listed at the third to fifth places, with 2843, 2575, and 2531 papers, respectively. The number of SCI papers published by Chinese organizations was close to that of the US and far more than those of other countries. The reason is probably that the SCI index paper publication was important in Chinese academic areas in recent years. The textile industry's technology and innovation have rapidly and vigorously developed because of industrial upgrade. The UK ranked third but only by a little more than one-third of that in the US. India is a developing country that performed outstandingly in this field, which might be the result of the development of Indian domestic biomedical textiles. In addition, Turkey, Japan, and South Korea also had great performance in the SCI paper publication.

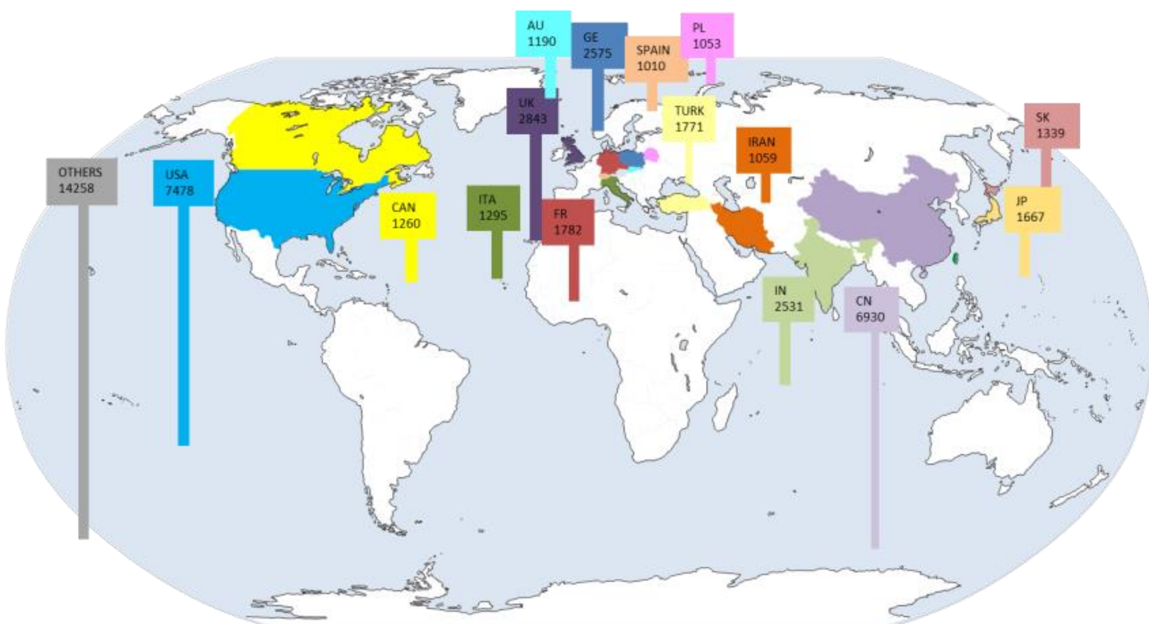


Fig. 6.7 Geographical distribution of searched SCI paper (2000–2015)

Fig. 6.8 shows the number of SCI paper publication by the UK textile academia by year. From 2000 to 2014, the number of publication was increasing yearly, especially from 2012 to 2014. However, data for 2015 are still being updated.

Fig. 6.9 shows that the material science and textile engineering research areas were listed as the top two strengths of the UK academia. Fig. 6.10 indicates that University of Manchester, University of Nottingham and University of Southampton are the top three universities with the most number of publications of updated innovation in textiles.

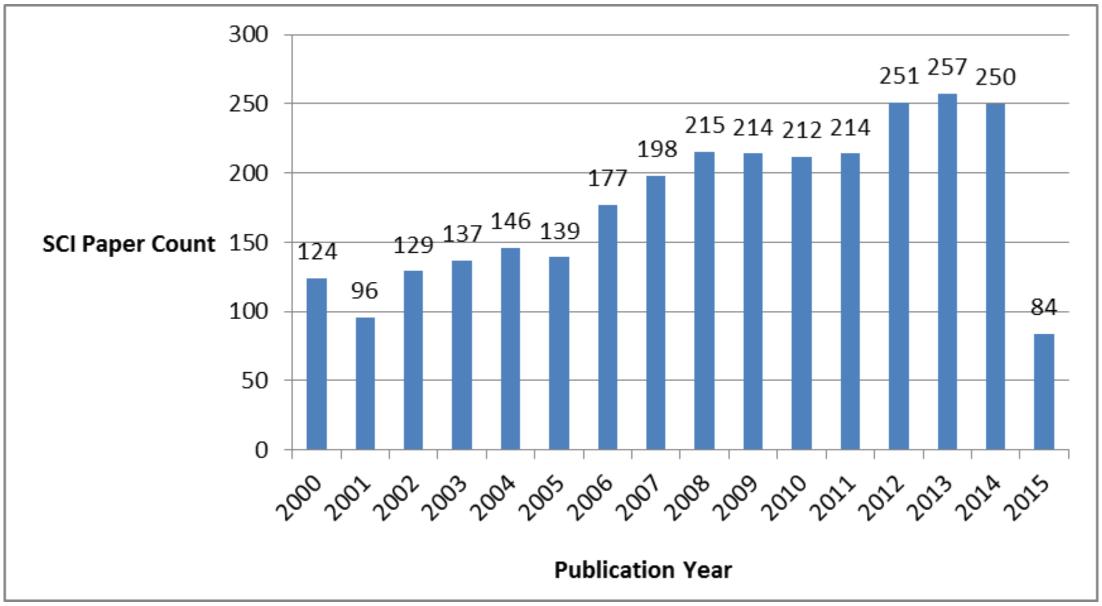


Fig. 6.8 SCI paper count by publication year in the UK

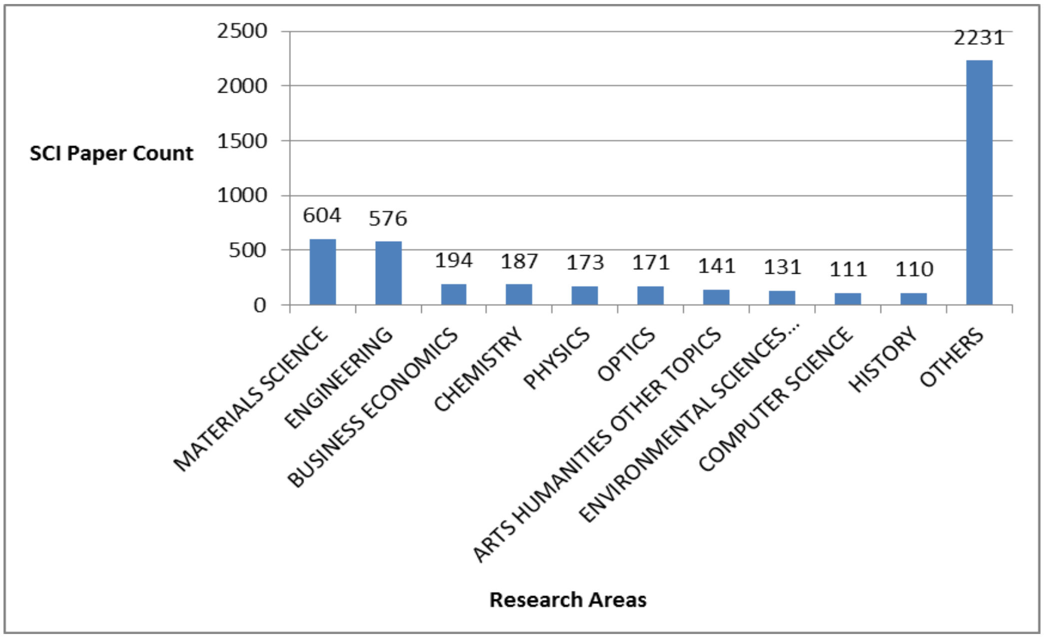


Fig. 6.9 SCI paper count by research area in the UK

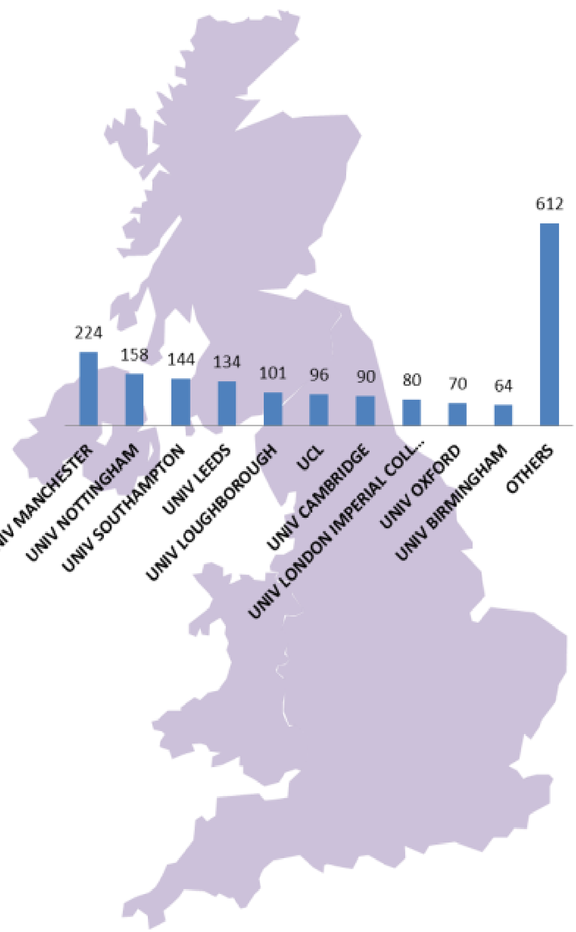


Fig. 6.10 SCI paper count by publication organization in the UK

Four rapidly developing firms of advanced smart textiles were analyzed in anonyms. Table 6.1 provides the general information and geographical locations.

Table 6.1 General information on four anonymous firms of smart textiles

Size	Area	Location	UK sector and number	Alliance project sector and number	Main product	Category
Micro	Greater Manchester	E08000003 Manchester	13990 - Manufacture of other textiles n.e.c.	10 OTH: Not elsewhere classified	Manufacture of smart garment technology	**S**martex **C**lothingtex
Micro	Greater Manchester	E08000003 Manchester	14190 - Manufacture of other wearing apparel and accessories n.e.c.	07 CMT: Clothing and apparel — Underwear & Outerwear	Manufacture of heated gloves	**S**martex **C**lothingtex
Small	Lancashire	E07000117 Burnley	13100 - Preparation and spinning of textile fibres	01 TEC: Spinning, Weaving, Knitted cloth	Knitting, dyeing and finishing of textiles.	**S**martex **C**lothingtex **M**aterial nonwovens & converting
Micro	Greater Manchester	E08000007 Stockport	14131 - Manufacture of other men's outerwear	07 CMT: Clothing and apparel — Underwear & Outerwear	Bluetooth clothing	**S**martex

Based on the assessment of the value, supply and innovation chains for the UK advanced textile industry, a SWOT analysis was developed as shown in Table 6.2.

Table 6.2 SWOT analysis of the UK Textile Industry

Internal Factors / External Factors	STRENGTH (S)	WEAKNESS (W)
	1. Solid traditional textile and clothing industrial foundation 2. Advanced technology and innovation 3. Strong educational resources 4. High quality and reputation products 5. Famous fashion brands 6. Innovative development of performance apparels	1. Fragmented supply chains 2. Small-scale companies 3. Insufficient labor force 4. Shortage of professionals 5. Aging and weak infrastructure 6. Lack of international marketing strategies 7. Inconvenient financial transfer 8. Lack of technology platform 9. E-business
OPPORTUNITIES (O)	**SO STRATEGY**	**WO STRATEGY**
1. Rapid market expansion within the world 2. Continuous development of technology 3. Opportunities in E-commerce 4. Development of E-based manufacturing and supply chain management 5. Development of E-finance 6. Development of technical textiles 7. Increase of health care du tot global population aging	Upgrade internal strength and exploit external opportunities 1. Increase core competence of traditional techniques/processing 2. Develop functional products with high added value 3. Develop industry and university cluster innovations 4. Exploit international markets 5. Brand management and strategic marketing 6. Participate in establishment of global industrial standards	Exploit external opportunities to overcome internal weakness 1. Establish database for global cooperation in supply chains 2. Develop industrial clusters 3. Introduce new positions in novel textile industry employments 4. Introduce updated worldwide information to the industry 5. Set up public technology service platforms to integrate different sectors in the new supply chains 6. Add new-trend areas into traditional textiles & clothing educations
THREATS (T)	**ST STRATEGY**	**WT STRATEGY**

1. Traditional raw materials shortage and price increase 2. Competitions in novel materials 3. Competitions in functional and innovative design 2. Increase of labor cost 3. Carbon emission control 4. Rapid development of developing countries 5. Impacts of E-business on traditional store-shopping mode 6. Globalization	Take advantage of internal strength and solve external threats 1. Research on functional materials 2. Research on fashion and function design 3. Research on carbon footprint and develop low-carbon economy 4. Attract high level professionals 5. Promote E-Fashion business 6. Establish market entrance standards for online products	Improve internal weakness and reduce external threat impact 1. Set up the UK special style in strong sectors in industrial chains 2. Large company leading or small-scale company alliance modes in innovation research 3. Establish training bases for technicians and management talents 4. Rebuild industrial image of textiles in domestic economy 5. Upgrade domestic infrastructure 6. Renew global marketing strategies

6.2.5 Industrial goals

6.2.5.1 Industrial gap

The industrial gap was the stark difference in labor cost between the UK and new industrializing countries. More than 80% of the UK's annual consumption of clothing and textile products is manufactured abroad. A strong shift to micro firms occurred, associated with a sharp decline in average firm size and the exit of medium and large firms. Therefore, the industry is in a vicious cycle of old equipment and poor capacity utilization and the supply chain is fragmented (Froud et al., 2017, p. 24; Li et al., 2016).

6.2.5.2 Research areas

The following 13 research areas were identified by the (Allianceproject, 2015b, p. 3):

- Agritex (textile products for the protection of agriculture, forestry, horticulture, and landscapes)
- Buildtex (innovative textiles for construction and architecture)
- Geotex (road construction, civil engineering, dam and waste site construction, coastal protection)
- Oeko-tex (products for environmental protection, waste minimization, and sustainable materials)
- Indutex (products for mechanical engineering and chemical and

electrical industries)

- Mobiltex (textiles for aerospace and automotive, railway, space, and marine applications)
- Novel materials (composite 3D materials, novel fibers and yarns)
- Clothtex (innovation in shoe & clothing manufacture, and digital fashion)
- Smart eTextiles (garments: combining textiles with a whole technology ecosystem)
- Hometex (innovation in furniture, upholstery, floor coverings, and carpets)
- Packtex (innovation in product packaging)
- Protex (innovation in personal and property protection)
- Medtex (innovation in medical and hygiene products, and industrial biotechnology)

6.2.5.3 Development strategy

Eight development strategies proposed were proposed (Allianceproject, 2015c, p. 19):

• Increased take-up of innovation support & increased rates of business innovation in SMEs

• More and better IP for UK companies

• More effective engagement between SMEs and higher education/research support

• Increased investment into key regions and across the sector

• Increased profile of the UK sector on the international stage

• Increased numbers of SMEs entering new international markets

• Stronger and more sustainable supply chains across the sector

• Creation of seamless skill provision from school to post-doctoral research

6.2.5.4 Key projects

Table 6.2 shows that 31 projects in eight research areas were proposed (Allianceproject, 2015c). However, only general ideas of the projects were mentioned. Specific project titles are recommended to make the industrial goals clear.

Table 6.2 Projects proposed by the Alliance Project Team

Research areas	**Project ideas**
Agri-textiles, Buildtex and Geotextiles	Crop cover and capillary matting
	Roofing and roof scrims
	Awnings, canopies, scaffold wrap
	Reinforcements
	Ground linings
Oekotex and Energy-textiles	Garments recycling
	Wearable technology
	Woven fabrics
	Extending lifetime of fibers

Indutex	Industrial filters and coated fabrics
	Drive and conveyor belting, webs
	Hose and gaskets
	Abrasives
Mobiltex	Vehicle, marine, aircraft, rail (exterior components, interior cabin, interior engine)
Clothing-tex, Smart Textiles and Garments, Sportex, Hometex	Healthcare/Medical/Fitness
	Automotive/Aerospace
	Protective/PPE/Military
	Interior textiles/Homewares
	Garment technologies
	Colouration, dyeing, and finishing
	Intelligent floorings
	Novel duvet and mattress fillings
Packtex	Woven sacks
	Netted sacks
Protex	Ballistics
	Fire services
	General consumer (sports)
Medtex	Wound care/prevention
	Prosthetics, body parts
	Clothing and protectives
	Auxetic materials

6.2.6 Key technology

6.2.6.1 Technology barrier

The technology barriers had been well analyzed in the Alliance Project reports. As stated, UK advanced textile manufacturing industry had its strength, such as solid traditional textile foundation and strong academic resources. However, it also had technological barriers to its growth, namely, fragile supply chain, outdated infrastructure, shortage of professionals, lack of technology collaboration platform, lack of e-business and financial transfer technology (Allianceproject, 2014, 2015a, 2015c; Froud et al., 2017).

6.2.6.2 Objectives of technology

The key objective of technology is to reshore and rebuild a sustainable textile industry in the UK (Allianceproject, 2014, 2015a). It aims to explore the viability of growth in parts of the UK textile industry, opportunities that can be supported, and how inhibitors can be overcome.

6.2.6.3 Current status of technology

Table 6.3 summarizes the ongoing projects in different research areas by academic research institutes (Allianceproject, 2015b). However, the specific status of relevant technology had not been further analyzed. The technology status of the industry, especially that of large-scale firms, should be also investigated.

Table 6.3 Ongoing projects by academic research institutes

Research areas	Research institute	Projects
Agri-textiles, Buildtex and Geo-textiles	University of Bristol	Fiber reinforced soils and geotechnical systems
	Leeds Metropolitan University	Geotechnics and environmental technologies, vegetable fiber geotextiles
	University of Manchester	Nonwovens and geotextiles, fiber and fabric mechanics and interactions
	University of Leeds	High performance textiles for geotechnical engineering and geotextiles
	University of Newcastle	Geotechnics and building structures—architectural textiles, soil modelling
Oekotex and Energy-textiles	University of Manchester	Sustainable textile materials, composition and dynamics of plant cellulose fibers
	University of Leeds (NIRI)	Nonwovens Institute: disassembly, waterless washing, and automotive recycling
	University of Huddersfield	Centre for Textile Thinking: sustainable textiles design, post-consumer waste, etc.
	University of Swansea	Heat, water, PV and bio-inspiration surface treatment (including textiles)
	University of Southampton	Energy harvesting materials for smart fabrics and interactive textiles
Indutex	Imperial College London	Development of new membrane filters with UoM, UoBath, UoNewcastle

	University of Bath	MAST Carbon Technologies: solvent recovery filter systems
Mobiltex	University of Leeds	NIRI automotive fibers, recycling, etc.
	University of Bristol	Multifunctional composites, novel microstructures, material mechanics, etc
	University of Plymouth	Advanced Composites Manufacturing Centre sustainable fiber composites
Novel Materials, Composites, and Fibers	University of Manchester	Fiber and fabric mechanics and National Composites Evaluation Facility
	University of Bristol (ACCIS)	Multifunctional composites, novel microstructures, auxetics, mechanics, etc.
	University of Cambridge	Macromolecular Materials Laboratories: material strength and conductivity
	University of Nottingham	Innovative Manufacturing Centre in Composites: modelling tools
	University of Leeds	NIRI disassembly, recycling, etc.
	University of Ulster	Woven 3D carbon fiber structures/axis composites spin-out
Clothing-tex, Smart Textiles and Garments, Sportex, Hometex	Nottingham Trent University	Embedded electronics in yarns, garment and fabric sensors, textile switches, etc
	University of Wales, Newport	Smart Clothes and Wearable Technology Research Centre—clothing systems
	Manchester Metropolitan Uni.	Performance sportswear fabrics, pressure sensors and wearable monitors
	University of Leeds	Colour imaging, textile colouration, graphics and appearance
	University of the Arts London	Designer Innovation Support Centre—production sourcing manufacturing
	Huddersfield Centre of Excellence	Signature DNA within yarn and fabrics, interior textiles, and branded apparel
	University of Southampton	Advanced electronic components (e.g., microcontrollers) within textile yarns
	University of Glasgow	Garment technology, flattening and sorting through robotics (Dextrous Blue)
	University of Exeter	Wearable light emitting transistors for future communication devices
	University of Loughborough	Wearable smart garments, functional antennas and associated electronics
	Heriot Watt University (RIfFM)	Research Institute for Flexible Materials. Clothing technology and manufacturing
Packtex	University of Glasgow	Garment technology, flattening and sorting through robotics (Dextrous Blue)
	University of Leeds (NIRI Ltd)	Nonwoven product packaging research and automotive sector product insulation
	University of Loughborough	Biodegradable packaging—(bio)polymer weathering and degradation
	Edinburgh Napier University	Extracting and refining bio-cell components to new bio-polymer based materials

Protex	University of Manchester	Engineered textiles and composites—ballistics/personal protection clothing
	University of Cranfield	Material and textiles armour group—survivability and forensic textile sciences
	University of Bolton (IMRI)	Fire retardancy and heat management
	University of Huddersfield	Armour Research Institute—forensic and material science
Medtex	University of Bolton (IMRI)	Medical devices and auxetic materials, anti-microbial textile treatments
	University of Leeds (CCTMIH)	Biotechnological modification of textiles, filtration and textile surface chemistry
	University of Manchester	Biomaterials and high performance technical textiles

6.2.6.4 Key technologies in short, medium, and long terms

Based on the discussions in the meeting of the joint research team as well as the expert forums, key technologies of medical textiles, smart textiles, and e-fashion to develop in the short, medium and long-terms were developed, respectively.

The template of key technology development in the short- to long-terms was developed by the author as a joint research member from the University of Manchester. As discussed in the expert forums, multiple disciplines are involved in medical and smart textiles and e-fashion. The supply chain infrastructure and IT platform were considered as the fundamental areas for industrial development. Figs. 6.11 to 6.13 show that supporting supply chain infrastructure, such as laboratories and facilities for product innovation, is placed on the first layer on the pyramid framework. On the second layer, IT platforms, such as cloud material database and computational modelling and simulation technology, were proposed as key technologies to develop. Key technologies for short-, medium-, and long-term innovation have also been proposed for medical and smart textiles and e-fashion.

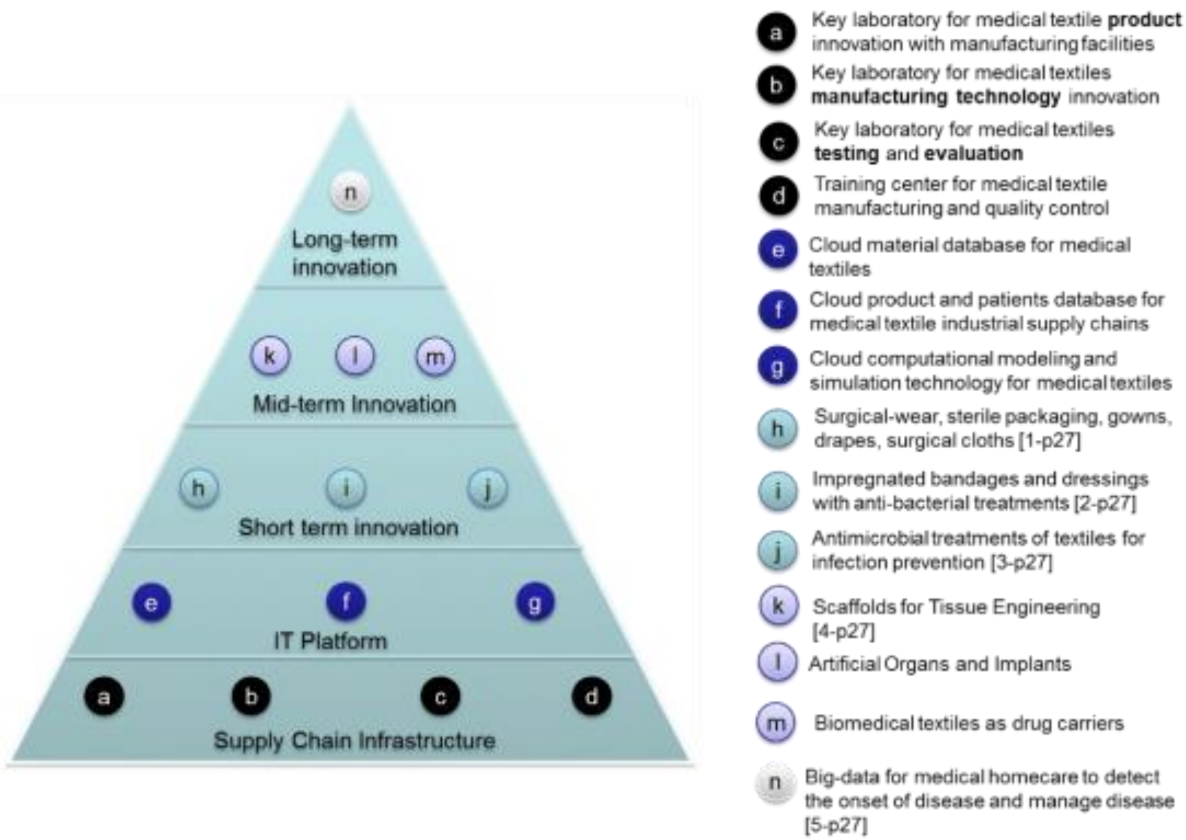


Fig. 6.11 Key technology of medical textile development in short to long terms

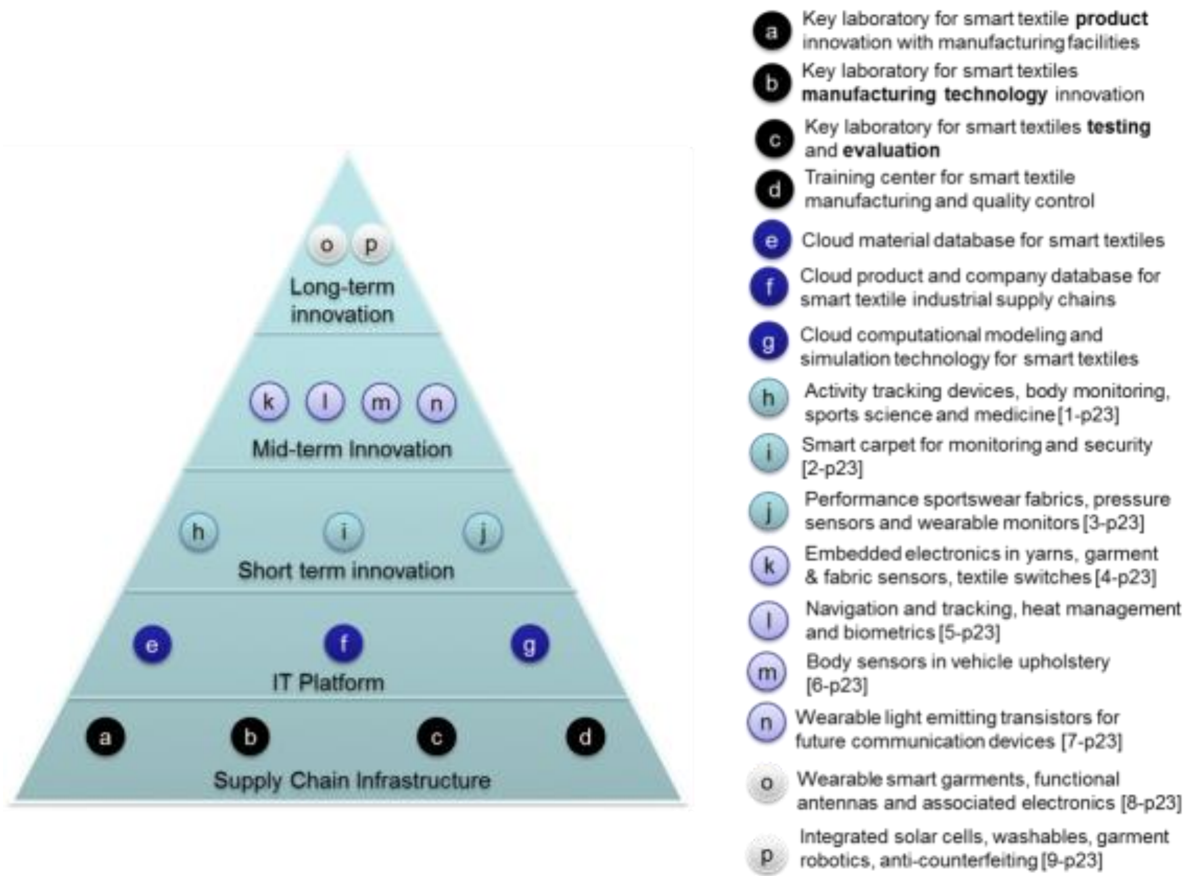


Fig. 6.12 Key technology of smart textile development in short to long terms

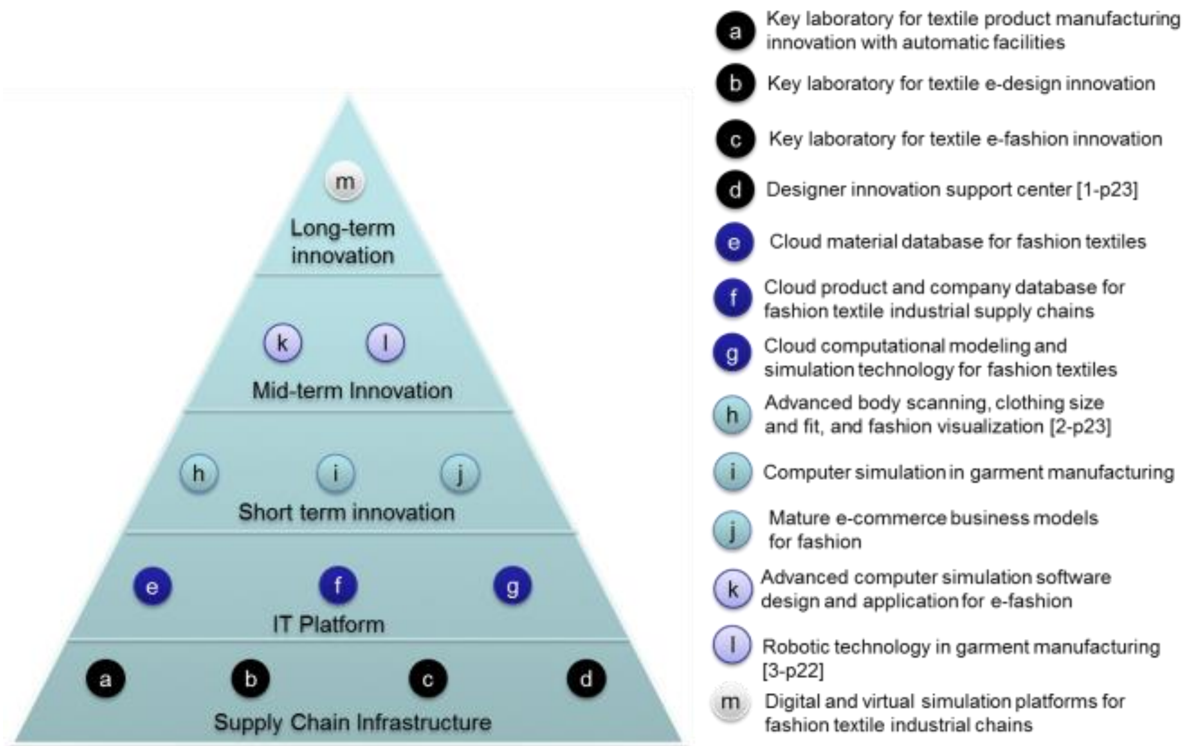


Fig. 6.13 Key technology of e-fashion development in short to long terms

The template of time lines was adopted based on the suggestions of the Alliance Project team, as shown in Figs. 6.14 to 6.16. The horizontal axis represents the time lines of technical challenges being fully addressed for the proposed key technologies while the vertical axis represents those of the fully entering market of the proposed key technologies.

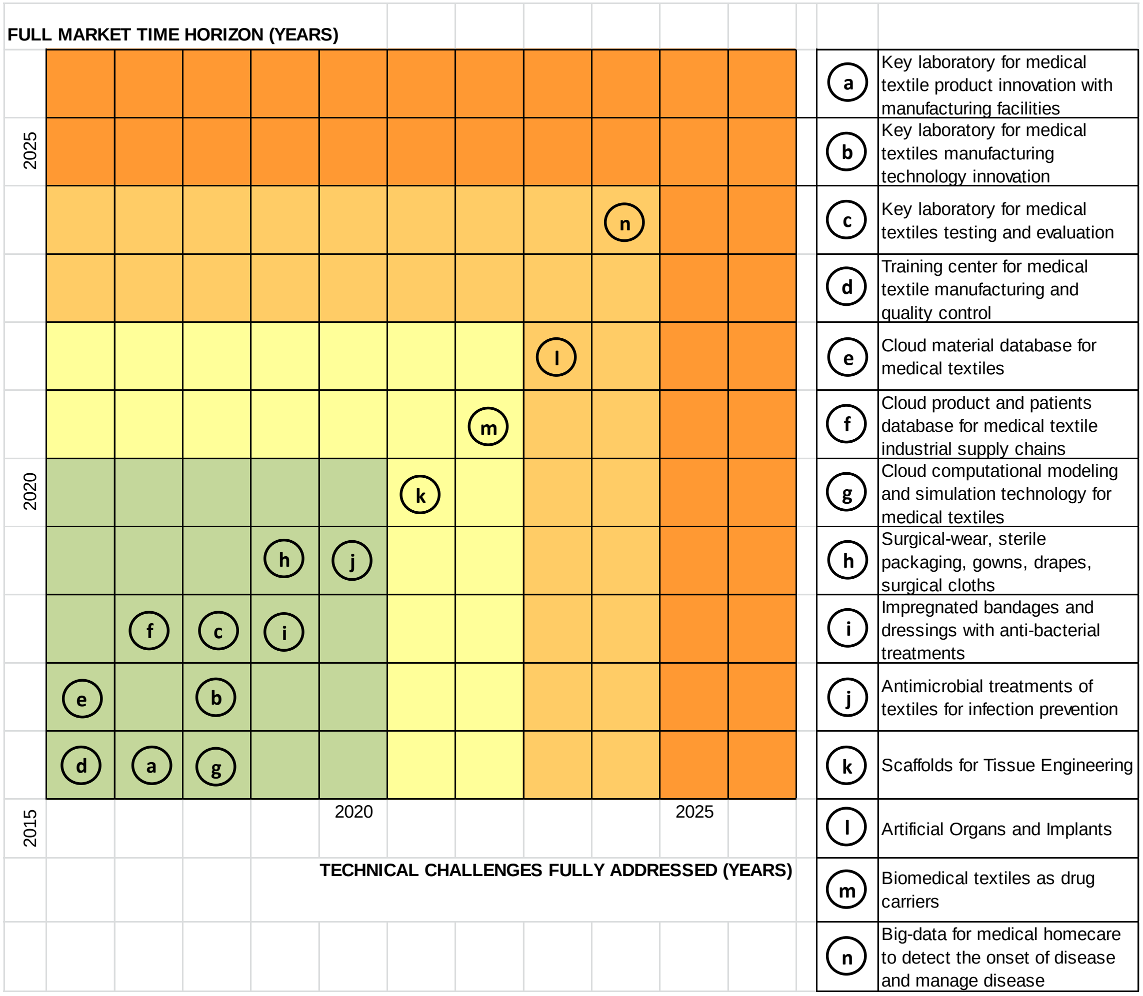
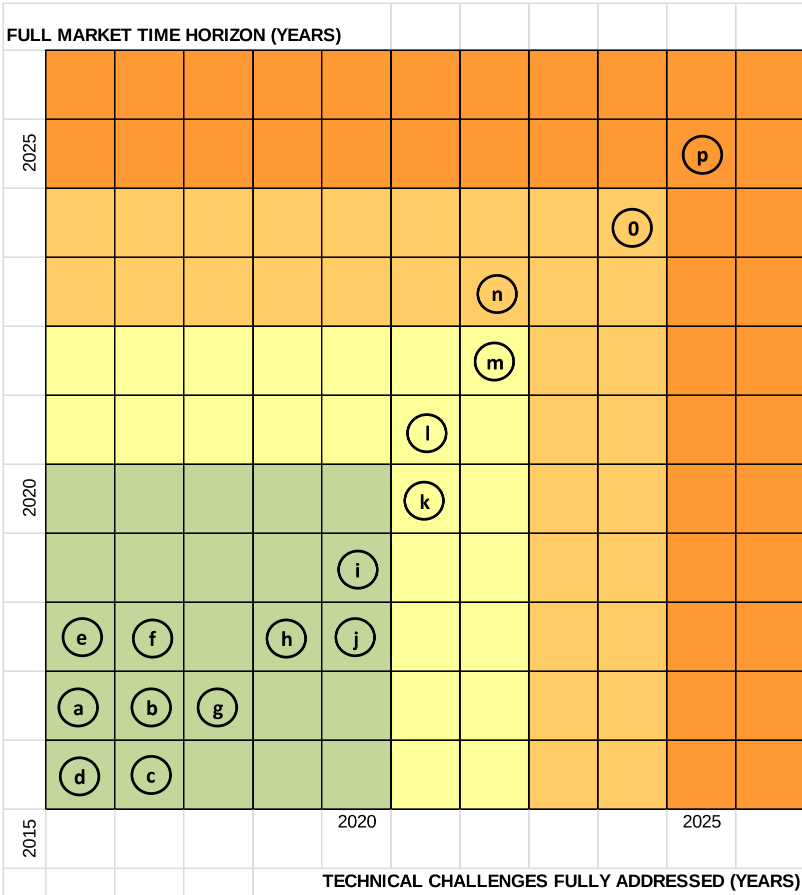


Fig. 6.14 Time lines for medical textile development



a	Key laboratory for smart textile product innovation with manufacturing facilities
b	Key laboratory for smart textiles manufacturing technology innovation
c	Key laboratory for smart textiles testing and evaluation
d	Training center for smart textile manufacturing and quality control
e	Cloud material database for smart textiles
f	Cloud product and company database for smart textile industrial supply chains
g	Cloud computational modeling and simulation technology for smart textiles
h	Activity tracking devices, body monitoring, sports science and medicine
i	Smart carpet for monitoring and security
j	Performance sportswear fabrics, pressure sensors and wearable monitors
k	Embedded electronics in yarns, garment & fabric sensors, textile switches
l	Navigation and tracking, heat management and biometrics
m	Body sensors in vehicle upholstery
n	Wearable light emitting transistors for future communication devices
0	Wearable smart garments, functional antennas and associated electronics
p	Integrated solar cells, washables, garment robotics, anti-counterfeiting

Fig. 6.15 Time lines for smart textile development

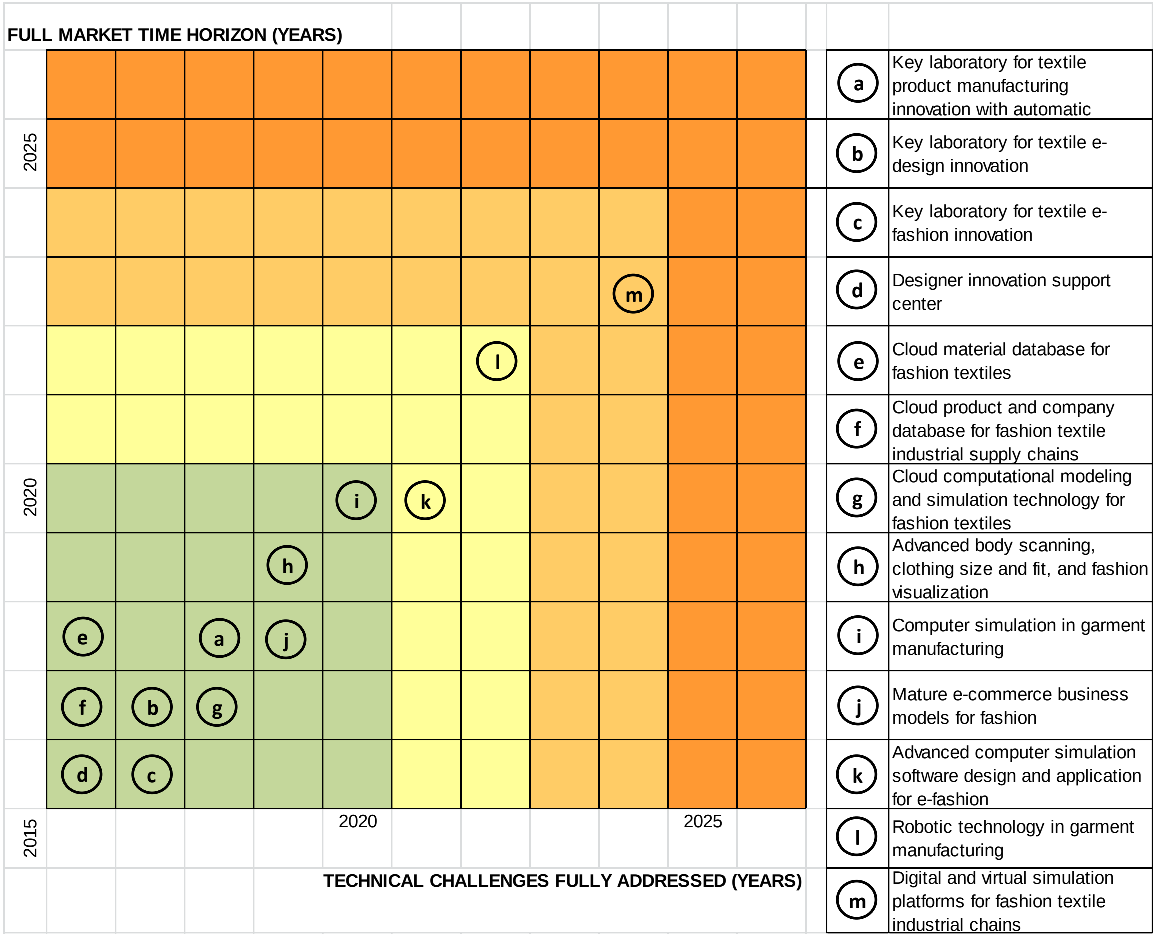


Fig. 6.16 Time lines for e-fashion development

6.2.7 Macro environment

6.2.7.1 Economic factors

The difficulty and opportunity for the UK textile industry under the macro-economic environment were well presented in the newly published report. It stated that textiles were not considered as “advanced manufacturing” and, therefore, they found it difficult to receive support from the UK governmental department. Nevertheless, recent interest was stirred, especially in Greater Manchester, on the extent to which textiles could be revived. This revival includes obtaining production back from overseas, following certain excitement about the reshoring phenomenon in the US (Froud et al., 2017, pp. 10-11). However, more information on the global macro-economic status that can influence the development of the UK textiles is recommended.

6.2.7.2 Societal challenges

The Alliance Project team has made a detailed analysis of societal challenges based on the industry, labor force, and industrial clusters. In terms of clusters, the main geographic concentrations included an area extending from Greater Manchester to West Yorkshire and South Lancashire (which is centred upon Rochdale, Oldham, Tameside and Kirklees) where textiles remain central to future manufacturing ambitions (Allianceproject, 2015a, p. 21).

6.2.7.3 Environmental protection

The environmental problem of the UK textiles and its corresponding solutions was reported. Textiles comprise around 3% of the 27 million tons of waste disposed each year in the UK. Environmentally-friendly materials, such as bio-fibres, recycling, bio-degradable, solar energy, and the sustainable use of natural resources are proposed for enhanced environmental management (Allianceproject, 2015b, p. 5). However, added environmental protection issues, such as recycling, are recommended for investigation.

6.2.7.4 Raw materials

The Alliance Project team also revealed that 81% of the firms surveyed experienced significant cost pressure from rising energy prices from 2013. The UK's weakness and strength were analyzed as "In an almost fully automated future manufacturing era, the UK is in disadvantage due to relatively high land and energy cost, but will likely benefit from a competitive advantage in terms of consumers' better trust of its products than those from its near-shore competitors such as Turkey" (Allianceproject, 2015a, pp. 50-51). However, the demand and supply of raw materials for the textiles have yet to be investigated.

6.2.7.5 Political, cultural, and lifestyle phenomena

The cultural and lifestyle phenomena were also analyzed. Several British interviewees expressed that repetitive factory work, such as machining, is considered unattractive to potential recruits who prefer retailing and other sectors offering similar levels of pay (Froud et al., 2017, p. 100). With different lifestyles, UK consumer behaviours have changed in various aspects, such as preferring cheaper imports offering more choices as well as improved value of products (Froud et al., 2017, p. 84), shopping through online websites and mobile apps and adoring fast fashion to keep up with the latest trends (Allianceproject, 2015a, p. 11). Based on these latest trends, the Alliance Project team proposed that high-end and mid-market apparel, fast fashion, luxury clothing and homeware products are strong areas for repatriation (Allianceproject, 2015a, p. 11).

6.2.7.6 Population

The influence of population development trend indicated that the worldwide demand for textiles is forecasted to increase due to the growing global population (Allianceproject, 2015a, p. 18). However, the aging population is recommended for further analysis because the structure of the population can also influence the demand for textile products.

6.2.8 Micro environment

6.2.8.1 Infrastructure

Outdated equipment in the textile industry was mentioned for a certain period. However, funding to support the renewal of equipment and infrastructure is limited. Certain innovative platforms, such as Community Clothing and Fashion Enter, were introduced as experimental cases to make up for the limitation in industrial infrastructure (Froud et al., 2017, p. 102). However, the demands and the corresponding suggestions for infrastructure development are recommended for further analysis.

6.2.8.2 Policy and agreement

The Alliance Project team has made satisfactory analysis of the policy and agreement for the textile industry. The disadvantageous position of the UK textile industry is that the May government's new industrial strategy of 2017 focused on 'world leading sectors of the future' which, of course, excludes textiles and other mundane activities (Froud et al., 2017, pp. 103-104). Therefore, formulating a variety of policies based on the analysis of specifics that address sub-sectorial issues was proposed (Froud et al., 2017, p. 111).

6.2.8.3 Investment

The status of investment from the government and industry for the UK textile was well analyzed. Certain sub-sectors of textiles claiming to be high tech and innovative in an attempt to unlock state funding are expected. The granting of government financial support through fund was politically important because investment grants recognized the continued existence of the textile sector and conceded that its activities had economic and social values (Froud et al., 2017, pp. 108-109).

6.2.8.3 Education and training

The status and demand for higher education and technical training for the UK textiles were also well investigated. Results show that higher education is very focused on fashion design, marketing, merchandising and retail (Froud et al., 2017, p. 101). A number of industrial-founded centres, such as the Fashion Enter, were introduced as providers of technical fashion modern apprenticeships in the UK (Froud et al., 2017, p. 103).

6.3 Development of the ITRMs

Based on the collaboration of the joint research team, the author develops an integrated, as well as individual, ITRM for the UK textile industry and biomedical textile sector, respectively. Figs. 6.17 and 6.18 depict the ITRMs.

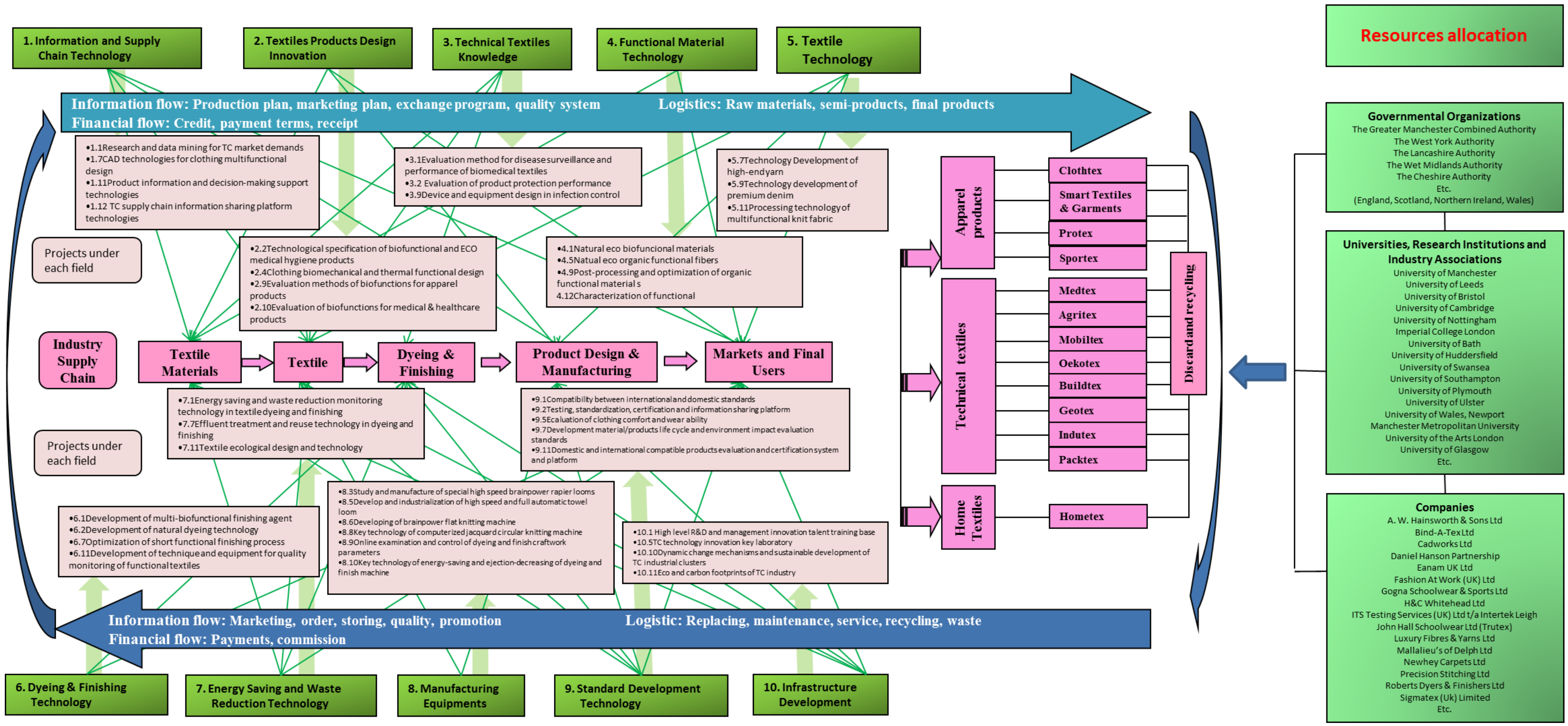


Fig. 6.17 An integrated ITRM for the UK textile industry

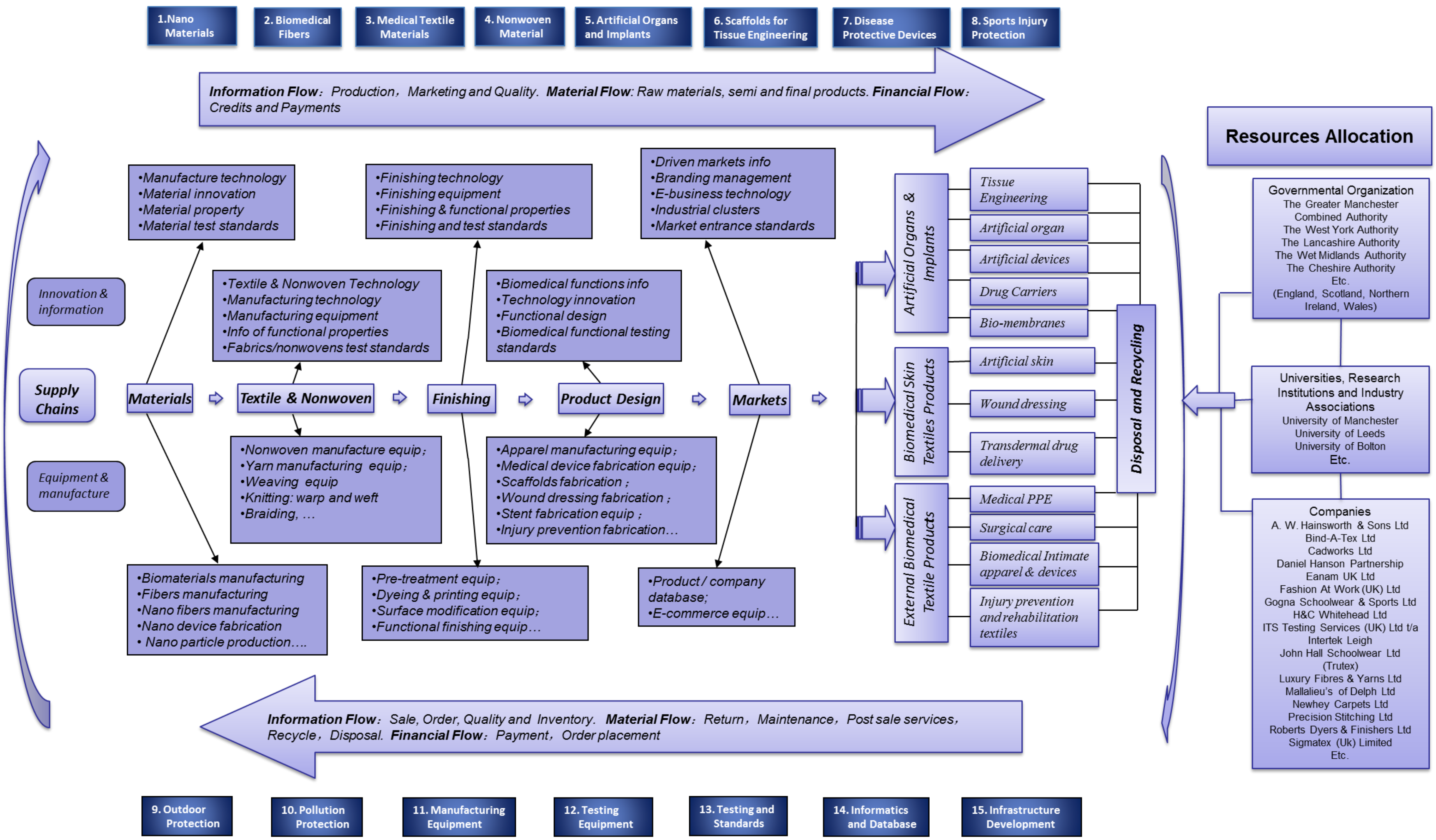


Fig. 6.18 An individual ITRM for the biomedical textile sector in the UK

6.4 Conclusion

Using the internal quality assessment model proposed in Chapter 3, the development process of UK advanced textile ITRM was described and assessed. New suggestions were made by the author as an actual practitioner of ITRM development. This chapter provides an illustration of the internal quality assessment of an ITRM during the development process, especially for the textile industry. Further case studies in different industries are highly recommended so as to improve generality of use. Moreover, the assessment of the UK advanced textile ITRM from the processes and contents may guide future practitioners in developing an effective ITRM as a specific sample.

Chapter 7 Conclusion

7.1 Summary of achievements

In this thesis, four existing textile ITRMs were assessed in terms of content quality (internal assessment) and actual performance (external assessment) using newly developed indices of quality and performance scores.

The first objective was fulfilled and the results were explained in Chapter 3. The major achievements included the following:

a) An internal assessment model, along with methods, was established to systematically assess the internal content quality of ITRMs.

b) A knowledge framework was built to present the intellectual understanding of the relationship among different attributes of the content quality.

c) Using quantitative parameters, the overall internal quality (Q_O), internal deficiency (D_I), and relative internal deficiency (RD_I) were developed for the internal quality measurement of ITRMs.

The proposed model and theoretical framework can contribute to the body of literature with an original assessment system that uses quantitative method for the internal content quality of ITRMs. This research opens a new chapter in the roadmap quality assessment supplementary to roadmapping techniques.

The research also fulfilled the second objective. Chapter 4 achieved the following:

a) An external assessment model was established to systematically assess the actual performances in terms of the conformance of the actual trends of industrial development within the target period and the original predictions from the ITRM.

b) A knowledge framework was generated to connect the different attributes of external assessment with corresponding internal quality assessment.

c) Real data statistics of the overall performance (P_O), external deficiency (D_E), and relative external deficiency (RD_E) was applied to measure the actual performance of ITRMs relative to that in the start year.

This chapter contributes to the original assessment system for evaluating the actual performance of ITRMs, complementing the previous roadmap performance assessment only by the judgments of concerned stakeholders.

The third objective was achieved through case studies and elaborated in both Chapters 3 and 4 with the following achievements:

a) The proposed internal assessment model was successfully applied to four textile ITRMs from different countries. Detailed measuring methods and steps were demonstrated. A lack of systematic framework for the presentation of ITRM contents was observed. Different organizations focused on distinct attributes in the development of ITRMs. Data sources were important to the quality of information collection and analysis.

b) Using the proposed external assessment model, the same four roadmaps were successfully evaluated based on the actual industrial statistics of their first five years compared with the corresponding predictions from the ITRMs in terms of their conformance levels. The original predictions of technology forces in three out of four ITRMs were weaker than their predictions of market forces. The overall performance scores and external deficiencies of ITRMs should complement each other. The smaller deficiency of performances between market and technology forces leads to a better overall performance of an ITRM. Academic resources were useful for satisfactory predictions of technology forces.

The four case studies confirmed the feasibility of the proposed internal and external assessment models. The findings will be useful to future ITRM development and assessment, especially for the textile industry.

The fourth objective was realized in Chapter 5 with the following achievements:

a) The relationship between internal quality and external performance was investigated with the collected data of the same four ITRMs. The results showed correlations between different variables, including the quality of industrial goals (Q_5) and overall performance (P_O), the performance of technology forces (P_{TF}) and the content quality of technology forces (Q_{TF}), the quality of technology forces (Q_{TF}) and external deficiency (D_E), the quality of technology forces (Q_{TF}) and relative external deficiency (D_{RE}), overall quality (Q_O) and external deficiency (D_E), and overall quality (Q_O) and relative external deficiency (D_{RE}).

b) Integrated guidelines for ITRM assessment were illustrated in the flowcharts.

This chapter integrated the internal and external assessment models to a system for ITRM assessment on both content and performance. The system provides the possibility to predict an ITRM's external performance by internal quality assessment. This research facilitates the necessary improvements for developing technology roadmapping.

In achieving the fifth objective, the success factors revealed in Chapters 3, 4, and 5 included the following:

a) Suitable methodology of industry technology roadmapping

b) Multi-organizational backgrounds for ITRM research team and expert panels

c) Systematic presentation of ITRM contents

d) Balanced contents for market and technology forces

e) Appropriate databases for information collection

f) Effectiveness of technology forces

g) Effectiveness of industrial goals

These success factors were generated from the practical assessment of actual cases, instead of subjective judgments or roadmapping experiences in the existing literature.

The sixth objective was fulfilled in Chapter 6 with the following achievements:

a) The development of the UK advanced textile ITRM, a lately developed roadmap, was assessed using the internal assessment model. The author, as a practitioner in that ITRM development team, made new suggestions.

b) An integrated ITRM for the UK textile industry was developed.

This chapter shows an example of implementing the internal quality assessment of an ITRM during development. The example may guide future practitioners in developing an effective ITRM, especially for the textile industry.

7.2 Limitations and future work

Only four textile ITRMs were available for assessment in this research. ITRMs in various industries can be assessed in the future to enhance the general use of the internal and external assessment models and the statistical analysis of internal quality and external performance.

The external performance data for the four ITRMs were only available in a five-year period at the time of conducting this research. Future assessments of these four ITRMs in a 10-year period can be conducted to investigate whether performances in a longer period produce different results.

Only four experts had been invited as internal quality raters for the content analysis of the selected ITRMs. Nevertheless, this number is acceptable in the research field of business and management (Duriau et al., 2007; Elo & Kyngäs, 2008; Lombard et al., 2002; Neuendorf, 2016). The difficulty for this research was finding experts specializing in textile science and engineering, with practical experience in technology roadmapping.

Appendix A

Table A-1a. Technology Roadmap Developed in the UK ITRM

	Environmental impacts	Social impacts	Life cycle of impacts	Geography of impacts	Relevance to material type		Development status		Market	
					Synthetic	Non-synthetic	Emerging	Established*	Niche	Mainstream
Computer aided design (CAD)	Reduction of waste and improved production efficiency	1) New skills and potential job creation and 2) potential for job loss from a more automated system.	Clothing production and garment assembly	Developed countries	✓	✓	×	✓	×	✓
Automated systems	1) Reduction of waste and 2) reduced harmful air and water emissions (more efficient processes)	1) New skills and potential job creation and 2) potential for job loss from a more automated system.	Clothing production and garment assembly	Developed countries	✓	✓	×	✓	×	✓
Biodegradable clothing	1) Reduces impact at end of life, but may produce methane if landfilled 2) uses materials that would have otherwise been wasted (sometimes) and 3) potential to offset resource consumption required for cotton cultivation and fossil fuel extraction	1) Potential job creation and 2) controversy over using food crops for non-food purposes	Raw material growth and end of life management	Affects local markets where produced	×	✓	✓	×	✓	×
'Smart' fibres	1) May affect end of life reuse and recycling options and 2) must be treated accordingly with the WEEE, RoHS and Battery Directives	1) New skills and potential jobs and 2) potential health and safety benefits for users	Clothing production and garment assembly, use and end of life management	Developed countries	✓	×	✓	×	✓	×

Table A-1b. Technology Roadmap Developed in the UK ITRM

	Environmental impacts	Social impacts	Life cycle of impacts	Geography of impacts	Relevance to material type		Development status		Market	
					Synthetic	Non-synthetic	Emerging	Established*	Niche	Mainstream
Fibre surface coating	1) Reduce the need for laundering, increased waste due to end of life management limitations caused by the coatings and 2) no evidence to confirm that consumers are treating clothing with coatings differently	Potential health impacts and/or perception of health impacts	Clothing production and garment assembly, use and end of life management	Global	✓	✓	×	✓	×	✓
RFID chips	Waste RFIDs will have to be treated accordingly with the WEEE, RoHS and Battery Directives	1) New skills and potential jobs and 2) controversy over privacy of consumers	Clothing production and garment assembly, distribution, retail and end of life management	Developed countries	✓	✓	✓	×	✓	×
Waterless cleaning	1) Reduces water consumption, 2) reduces need for tumble drying and 3) may be useful in areas with water shortages	1) New skills and potential jobs and 2) increase life span of clothing	Use	Developed countries	✓	✓	✓	×	✓	×
Non-solvent dry cleaning	Reduces use of toxic chemicals	1) New skills and potential jobs and 2) increase life span of clothing	Use	Developed countries	✓	✓	×	✓	✓	×
Textile colouration technologies	1) Reduces use of some toxic dyes and 2) reduced quantity required	1) New skills and potential jobs and 2) health and safety increased from using less toxic dyes	Fibre production, clothing production and garment assembly	Developed countries	✓	✓	×	✓	×	✓
Clothing recycling and reuse technologies	1) Increased sorting efficiency, 2) increased ease of recycling fibres and 3) energy savings	1) Job creation and 2) provides a source of affordable clothing to developing countries	Fibre production and end of life management (if recycling occurs)	Global	✓	✓	×	✓	✓**	✓**

* Established technologies are still be further developed

** Niche in developing countries, mainstream in developed countries

Table A-2. Technology Roadmap Developed in the Canadian ITRM

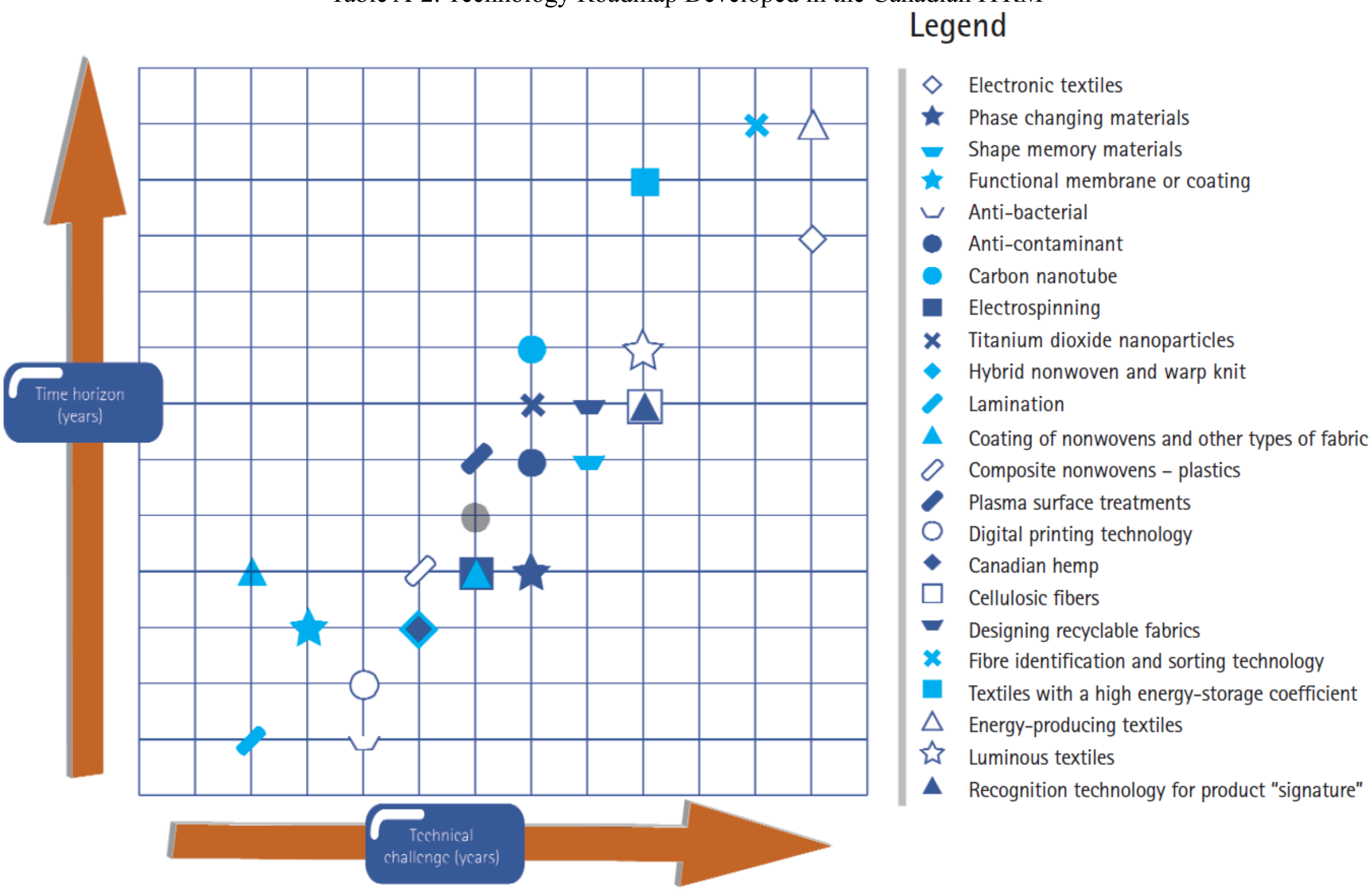
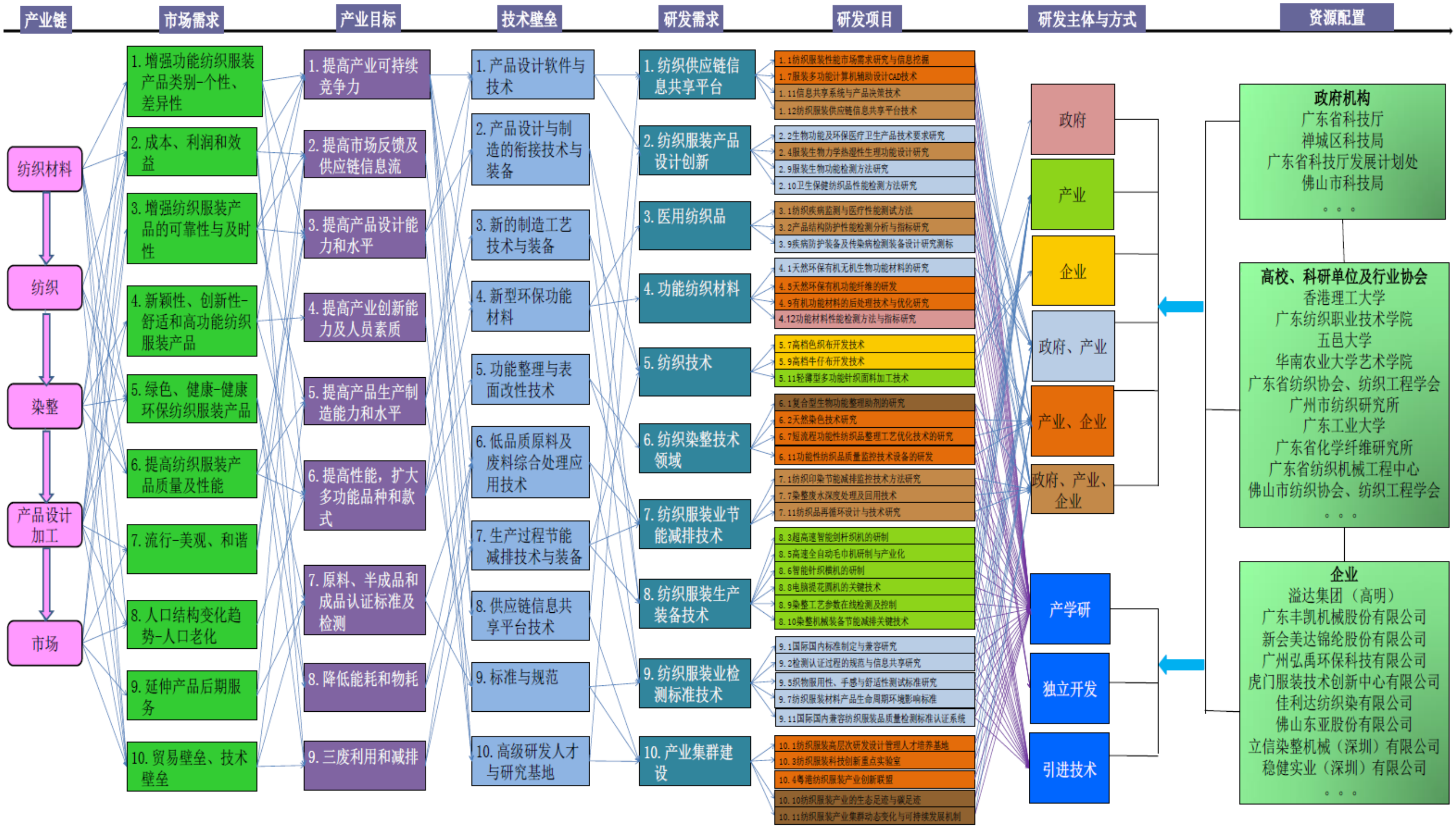


Table A-3. Technology Roadmap Developed in the US ITRM

Present (2009)	Barriers & Solutions	Future Goal (2019)
Size-based flushable wipes & Flushable wipes -Adult moist tissue -Toddler training wipes -Feminine hygiene wipes	Market (Consumers' unawareness and indifference on flushability) • Consumer education - Transfer consumer behavior from dry tissue to wet wipes - Make consumers understand what can be flushed and what cannot be • Use of flushability labels Infra-structure (Old and pulp-orient-designed systems, Decrease of water usage) • Improvement of wipes to be compatible with waste water systems - Develop wipes technology - Monitor changes of waste water treatment systems/technologies • Improvement of INDA/EDANA guidelines • Infrastructure to test guidelines Regulation (Introduction of new regulations and standards) • Prevent future regulations - Improve INDA/EDANA guidelines - Development of wipes technologies • Entire industry's participation in meeting INDA/EDANA guidelines • Use of flushability labels • Collaborations with toilet manufacturers Technology (Rack of technology & R&D resources, IP protection) • Good wet strength in usage and no strength when flushed • Binder and fiber technologies - Reversible binders and their conditions - Biodegradable, short fibers and fibers broken down shortly • Possess current properties of wet wipes (softness and bulk) • Environmentally friendly ingredients • Best combination of components • Detour intellectual property • Increase companies' R&D capability	**Truly flushable Pre-moistened Nonwoven Wipes** -Expand markets to new applications - Adult moist tissue - Toddler training wipes - Feminine hygiene wipes - Cosmetic wipes - Adult incontinence/ bathing wipes - Bathroom cleaning wipes

Table A-4. Technology Roadmap Developed in the Chinese ITRM



Appendix B

Table B. Rubrics for content assessment

No.	Internal Assessment Criterion		Rubrics 1	2	3	4	5
1	Internal Legitimacy	Definitions of TRM, methodology, roadmap development process	**not** mentioned nor stated clearly.	**unclear** concepts or methodologies.	stated **clearly**.	stated **clearly with detailed plan**.	stated **clearly with detailed plan and meet scientifically rigorous requirements with references and critical analysis**.
		Level of authority of expert panels	**No** reputable professionals from academia or industry	**Some** reputable professionals from academia or industry from **local and regional community**.	**Balanced** reputable professionals from academia and industry from **local and regional community**	**Balanced** reputable professionals from academia and industry from **local and regional and national community**	**Balanced** reputable professionals from academia and industry from **local, regional, national and international community**
		Level of authority of research team	**No** reputable professionals from academia	**Some** reputable professionals from academia or industry from **local and**	**Balanced** reputable professionals from academia and industry from	**Balanced** reputable professionals from academia and industry from **local and regional and**	**Balanced** reputable professionals from academia and industry from **local, regional, national and**

			or industry	**regional community**	**local and regional community**.	**national community**	**international community**
2	Value Chain	The price index and value addition for each segment including raw materials, fabric processing, design, clothes processing, marketing and recycle	**not** identified nor analyzed.	**partially** identified and analyzed.	**systematically** identified and analyzed.	**systematically** identified and analyzed with **convincing evidence.**	**systematically** identified and analyzed with **convincing evidence and sound references**.
3	Suppl y Chain	The supply and demand status among segments, such as leading actors, clusters, industrial scale, production capacity, logistics etc.	**not** identified nor analyzed.	**partially** identified and analyzed.	**systematically** identified and analyzed.	**systematically** identified and analyzed with **convincing evidence.**	**systematically** identified and analyzed with **convincing evidence and sound references**.
4	Innov ation Chain	The technology innovation capacity and innovation clusters among segments, such as innovation input, R&D power of industry and academia, innovative projects, industrial clusters, cooperation ways etc.	**not** identified nor analyzed.	**partially** identified and analyzed.	**systematically** identified and analyzed.	**systematically** identified and analyzed with **convincing evidence**.	**systematically** identified and analyzed with **convincing evidence and sound references**.

5	Industrial Goals	Identification of industrial gap	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		Identification of research areas	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		Identification of development strategy	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		Identification of key projects	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
6	Key Technology	Identification of technology barrier/gap	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.

		Identification of objectives of technology	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		Identification of current status of technology	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		Identification of key technologies to be developed in short, medium and long terms	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
7	Macro enviro nment	The external economic threats/shocks for business firms from structure, conduct and performance aspects	**not** identified and analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		The societal challenges that can influence the industry directly, including industrial basis, labour force, geographical distributions of sectors, residential	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.

		living level and requirements etc.					
		The impacts of industrial chains on environment and requirements and solutions for ecological protection and balance	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		The resources of raw materials, energy, water and others, their supply, demands, distributions and regions of origin	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		The key political, cultural and lifestyle elements and their changing trends	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		The key structural features and changing trends of human population	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
8	Micro enviro nment	The current status and future demands of infrastructural facilities and platforms, including platforms for product,	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.

		information and finance, quality control and management and transport facilities, etc.					
		Existing policies and relevant international agreements in the nations/regions	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		The structure and trends of capital investments from governments and industries/regions	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.
		The demands and trends of training and educational resources, and key effects of higher education and professional training that can influence the industry directly	**not** identified nor analyzed.	**partially** identified and analyzed.	**thoroughly** identified and analyzed.	**thoroughly** identified and analyzed with **convincing evidence**.	**thoroughly** identified and analyzed with **convincing evidence and sound references**.

References

Albright, R. E. & Kappel, T. A. (2003). Technology roadmapping: Roadmapping the corporation. *Research Technology Management,* 46**,** 11.

Allan, A., Edenfeld, D., Joyner, W. H., Kahng, A. B., Rodgers, M. & Zorian, Y. (2002). 2001 Technology Roadmap for Semiconductors. *Computer,* 35**,** 42-53.

Alliance Project. (2014). The Revival of The UK Textiles Industry. Retrieved from http://www.neweconomymanchester.com/alliance-project-report-revival-textile-final.pdf. [Accessed on 15 March 2017]

Alliance Project. (2015a). Repartiation of UK Textile Manufacture. Retrieved from http://www.neweconomymanchester.com/media/1467/3234-j2747-alliance-project-report-lb-low-final.pdf. [Accessed on 15 March 2017]

Alliance Project. (2015b). Research and Development and Innovation in UK Textiles. Report from the alliance project team.

Alliance Project. (2015c). Toward a strategy for UK textiles innovation. Report from the alliance project team.

Amer, M. & Daim, T. U. (2010). Application of technology roadmaps for renewable energy sector. *Technological Forecasting and Social Change,* 77**,** 1355-1370. . doi:10.1016/j.techfore.2010.05.002

Arden, W. (2002a). Future roadblocks and solutions in silicon technology as outlined by the ITRS roadmap. *Materials Science in Semiconductor Processing,* 5**,** 313-319. doi:10.1016/s1369-8001(02)00131-2

Arden, W. (2002b). The International Technology Roadmap for Semiconductors

- Perspectives and challenges for the next 15 years. *Current Opinion in Solid State and Materials Science,* 6**,** 371-377.

Arden, W. (2006). Future semiconductor material requirements and innovations as projected in the ITRS 2005 roadmap. *Materials Science and Engineering: B,* 134**,** 104-108. doi:10.1016/j.mseb.2006.07.004

Arntzen, B. C., Brown, G. G., Harrison, T. P. & Trafton, L. L. (1995). Global supply chain management at Digital Equipment Corporation. *Interfaces,* 25**,** 69-93.

Austin, J. T. & Bobko, P. (1985). Goal ‐ setting theory: Unexplored areas and future research needs. *Journal of Occupational Psychology,* 58**,** 289-308.

Bakeman, R. (2000). Behavioral observation and coding. *Handbook of research methods in social and personality psychology***,** 138-159.

Baldwin, R. (2011). *Trade and industrialisation after globalisation's 2nd unbundling: How building and joining a supply chain are different and why it matters.* National Bureau of Economic Research.

Baldwin, R. & Lopez ‐ Gonzalez, J. (2015). Supply ‐ chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses. *The World Economy,* 38**,** 1682-1721.

Beck, T. (2000). *Financial structure and economic development: Firm, industry, and country evidence* (Vol. 2423). World Bank Publications.

Black, D. & Henderson, V. (1999). Spatial evolution of population and industry in the United States. *The American Economic Review,* 89**,** 321-327.

Blalock, G. & Veloso, F. M. (2007). Imports, productivity growth, and supply chain learning. *World Development,* 35**,** 1134-1151.

Borrell-Damian, L. (2009). *Collaborative doctoral education: university-industry partnerships for enhancing knowledge exchange; doc-careers project*. European University Association Brussels.

Brizius, J. A. & Campbell, M. D. (1991). *Getting Results: A Guide for Government Accountabiblity*. Council of Governors Policy Adivisors.

Burnard, P. (1996). Teaching the analysis of textual data: an experiential approach. *Nurse education today,* 16**,** 278-281.

Business Dictionary (2017). Technological forces. Retreved from: http://www.businessdictionary.com/definition/technological-forces.html [Accessed on Feb 26, 2017].

Caetano, M. & Amaral, D. C. (2011). Roadmapping for technology push and partnership: A contribution for open innovation environments. *Technovation,* 31**,** 320-335. doi:10.1016/j.technovation.2011.01.005

Cambridge Dictionary (2017). Meaning of "content" in the English Dictionary. Cambridge University Press.

Carpenter, M. P. & Narin, F. (1981). The adequacy of the Science Citation Index (SCI) as an indicator of international scientific activity. *Journal of the American Society for Information Science,* 32**,** 430-439.

Carvalho, M. M., Fleury, A. & Lopes, A. P. (2013). An overview of the literature on technology roadmapping (TRM): Contributions and trends. *Technological Forecasting and Social Change,* 80**,** 1418-1437. doi:10.1016/j.techfore.2012.11.008

Chen, K., Lin, Q. & Wu, J. (2010). *Science & technology on public health in China a roadmap to 2050.* Beijing : Science Press.

Chen, Y. (2010). *Energy science & technology in China a roadmap to 2050.* Beijing : Science Press.

Cooper, R. G. (1979). Identifying industrial new product success: Project NewProd. *Industrial Marketing Management,* 8**,** 124-135.

Costa, O. D., Boden, M. & Friedewald, M. (2005). Science and technology roadmapping for policy intelligence : lessons for future projects. Second Prague Workshop On Futures Studies Methodology.

CTT Group (2008). Technology roadmap for Canadian textile industry. Retrieved from: https://www.ic.gc.ca/eic/site/trm-crt.nsf/vwapj/textile-textiles_eng.pdf/$file/textile-textiles_eng.pdf. [Accessed on Feb 26, 2016].

Daim, T. U. & Oliver, T. (2008). Implementing technology roadmap process in the energy services sector: A case study of a government agency. *Technological Forecasting and Social Change,* 75**,** 687-720. doi:10.1016/j.techfore.2007.04.006

Dewey, M. E. (1983). Coefficients of agreement. *The British Journal of Psychiatry,* 143**,** 487-489.

Dong, X. Y. & Putterman, L. (2003). Soft budget constraints, social burdens, and labor redundancy in China's state industry. *Journal of Comparative Economics,* 31**,** 110-133.

Downe W. B. (1992). Content analysis: method, applications, and issues. *Health care for women international,* 13**,** 313-321.

Dunning, J. & Narula, R. (2003). *Foreign direct investment and governments: catalysts for economic restructuring*. Routledge.

Duriau, V. J., Reger, R. K. & Pfarrer, M. D. (2007). A content analysis of the content analysis literature in organization studies: Research themes, data sources, and methodological refinements. *Organizational research methods,* 10**,** 5-34.

New Economy. (2015). The Alliance Project. Retrieved from: http://neweconomymanchester.com/our-work/business-innovation-science/enterprise/the-alliance-project. [Accessed on 20 Jan 2016].

Edenfeld, D., Kahng, A. B., Rodgers, M. & Zorian, Y. (2004). 2003 technology roadmap for semiconductors. *Computer,* 37**,** 47-56.

Elo, S. & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing,* 62**,** 107-115.

EIRMA. (1997). *Technology Roadmapping: Delivering Business Vision*. EIRMA.

Erdener, C. B. & Dunn, C. P. (1990). Content analysis. *Mapping strategic thought***,** 291-300.

Farrukh, C., Phaal, R. & Probert, D. (2003). Technology roadmapping: linking technology resources into business planning. *Int. J. of Technology Management,* 26. doi:10.1504/IJTM.2003.003140

Ford, D. & Ryan, C. (1981). Taking technology to market. *Harv. Bus. Rev.;(United States),* 59.

Foxon, T. J., Gross, R., Chase, A., Howes, J., Arnall, A. & Anderson, D. (2005). UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. *Energy policy,* 33**,** 2123-2137.

Franken, J. (2013). 2012 Roll Goods Import/Export Data. Nonwoven Industry. Retrieved from: http://www.nonwovens-industry.com/issues/2013-05/view_capitol-comments/2012-roll-goods-importexport-data.

[Accessed on 10 May 2017].

Frey, L., Botan, C. H. & Kreps, G. (2000). *Investigating communication.* NY: Allyn & Bacon.

Frost, J. (2015). Choosing Between a Nonparametric Test and a Parametric Test. Retrieved from: http://blog.minitab.com/blog/adventures-in-statistics-2/choosing-between-a-nonparametric-test-and-a-parametric-test. [Accessed on 13 May 2017]

Froud, J., Hayes, S., Wei, H. & Williams, K. (2017). Coming Back? Capability & Precarity in UK Textiles & Apparel. Retrieved from: https://foundationaleconomycom.files.wordpress.com/2017/02/coming-back-capability-and-precarity-in-uk-textiles-and-apparel-march-2017.pdf. [Accessed on 15 March 2017].

Galvin, R. (1998). Science roadmaps. *SCIENCE,* 280**,** 2.

Garcia, M. L. (1997). Introduction to technology roadmapping: The semiconductor industry association`s technology roadmapping process. Paper prsented at Pbd: Apr.

Garcia, M. L. & Bray, O. H. (1997). Fundamentals of technology roadmapping.US: Sandia National Labs.

Gerdsri, N. (2007a). An analytical approach to building a technology development envelope for roadmapping of emerging technologies. *International Journal of Innovation and Technology Management,* Vol.4**,** p121-135.

Gerdsri, N. (2007b). Technology roadmapping. Retrieved from: http://www.insighttrm.com/area7.php. [Accessed on 11 Feb 2017].

Gerdsri, N. & Assakul (2007). Key Success Factors for Initiating Technology Roadmapping (TRM) Process: A Case Study of a Leading Thai Firm.

ASIA Pacific Academy of Management and Business Conference (APAMB) Singapore.

Gerdsri, N., Vatananan, R. S. & Dansamasatid, S. (2009). Dealing with the dynamics of technology roadmapping implementation: A case study. *Technological Forecasting and Social Change,* 76**,** 50-60.

Gereffi, G., Humphrey, J. & Kaplinsky, R. (2001). Introduction: Globalisation, value chains and development. *IDS bulletin,* 32**,** 1-8.

Geum, Y., Lee, S., Kang, D. & Park, Y. (2011). Technology roadmapping for technology-based product–service integration: A case study. *Journal of Engineering and Technology Management,* 28**,** 128-146.

Griliches, Z. (2007). R&D, patents and productivity. University of Chicago Press.

Groenveld, P. (1997). Roadmapping integrates business and technology. *Research-Technology Management,* 40**,** 48-55.

Groenveld, P. (2007). Roadmapping Integrates Business and Technology. *Research Technology Management,* 50**,** 10.

Guo, H. & Wu, J. (2010). Space science & technology in China a roadmap to 2050. Beijing : Science Press.

Habert, G., De Lacaillerie, J. D. E. & Roussel, N. (2011). An environmental evaluation of geopolymer based concrete production: reviewing current research trends. *Journal of cleaner production,* 19**,** 1229-1238.

Hall, R. E. (1988). Intertemporal substitution in consumption. *Journal of political economy,* 96**,** 339-357.

Hansen, M. T. & Birkinshaw, J. (2007). The innovation value chain. *Harvard* *business review,* 85, 121.

Herstatt, C. & Lettl, C. (2004). Management of" technology push" development projects. *International Journal of Technology Management,* 27, 155-175.

Hillebrandt, P. M. (1985). *Economic theory and the construction industry*. Springer.

Horsch, K. (1997). Indicators: Definition and Use in a Results-Based Accountability System. Retrieved from: http://www.hfrp.org/publications-resources/browse-our-publications/indicators-definition-and-use-in-a-results-based-accountability-system. [Accessed 2 May 2017].

Horvath, L. (2001). Collaboration: the key to value creation in supply chain management. *Supply Chain Management: An International Journal,* 6, 205-207.

Hsieh, H. F. & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research,* 15, 1277-1288.

Hu, J. Y., Li, Y., Zeng, L. & Muthu, S. S. (2010a). Medical Textiles Technology Roadmap for Guangdong Textile and Clothing Industry. *Textile Bioengineering and Informatics Symposium Proceedings* 2010.

Hu, J. Y., Li, Y., Zeng, L. & Muthu, S. S. (2010b). Testing Standard Technology Roadmap for Guangdong Textile and Clothing Industry. *Textile Bioengineering and Informatics Symposium Proceedings* 2010.

Industry-Canada. (2005). Technology roadmap: lumber and value-added wood products. Retrieved from: http://strategis.ic.gc.ca/epic/internet/infi-if.nsf/en/fb01315e.html. [Accessed August 22 2015].

Industry-Canada. (2008). *T*echnology Roadmap for the Canadian Textile

Industry. Retrieved from: http://www.ic.gc.ca/eic/site/trm-crt.nsf/eng/rm00359.html 2008. [Accessed August 22 2015].

Jain, K. & Sekar, R. (2000). User-Level Infrastructure for System Call Interposition: A Platform for Intrusion Detection and Confinement. NDSS.

Jeffrey, H., Sedgwick, J. & Robinson, C. (2013). Technology roadmaps: An evaluation of their success in the renewable energy sector. *Technological Forecasting and Social Change,* 80**,** 1015-1027. doi:10.1016/j.techfore.2012.09.016

Jennings, N. R., Sycara, K. & Wooldridge, M. (1998). A Roadmap of Agent Research and Development. *Autonomous Agents and Multi-Agent Systems,* 1**,** 7-38.

Johnson, R. C. & Noguera, G. (2012). Accounting for intermediates: Production sharing and trade in value added. *Journal of international Economics,* 86**,** 224-236.

Jonsson, A. & Svingby, G. (2007). The use of scoring rubrics: Reliability, validity and educational consequences. *Educational research review,* 2**,** 130-144.

Kajikawa, Y., Usui, O., Hakata, K., Yasunaga, Y. & Matsushima, K. (2008). Structure of knowledge in the science and technology roadmaps. *Technological Forecasting and Social Change,* 75**,** 1-11. doi:10.1016/j.techfore.2007.02.011

Kaplinsky, R. & Morris, M. (2001). *A handbook for value chain research*. IDRC Ottawa.

Keegan, A. & Turner, J. R. (2002). The management of innovation in project-based firms. *Long range planning,* 35**,** 367-388.

Kim, M. J. (2009). *Industry technology roadmap for the flushable pre-moistened nonwoven wipes industry.* Thesis for Doctor of Philosophy Degree, North Carolina State University.

Kirchain, R. & Kimerling, L. (2007). A roadmap for nanophotonics. *Nature Photonics,* 1**,** 303-305.

Kolbe, R. H. & Burnett, M. S. (1991). Content-analysis research: An examination of applications with directives for improving research reliability and objectivity. *Journal of consumer research,* 18**,** 243-250.

Koskela, L. & Howell, G. (2002). The underlying theory of project management is obsolete. *Proceedings of the PMI Research Conference*. PMI, 293-302.

Kostoff, R. N., Boylan, R. & Simons, G. R. (2004). Disruptive technology roadmaps. *Technological Forecasting and Social Change,* 71**,** 141-159.

Kostoff, R. N. & Schaller, R. R. (2001). Science and technology roadmaps. *IEEE Transactions on Engineering Management,* 48**,** 132-143.

Kotler, P. & Keller, K. L. (2006). Marketing management 12e. *New Jersey*.

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology*. Sage.

Laat, B. D. & Mckibbin, S. (2003). The Effectiveness of Technology Road Mapping — Building a Strategic Vision. Report on *Ministry of Economic Affairs*. Retrieved from www.ez.nl.[Accessed on 22 June 2016].

Lahiri, N. (2010). Geographic distribution of R&D activity: how does it affect innovation quality? *Academy of Management Journal,* 53**,** 1194-1209.

Landis, J. R. & Koch, G. G. (1977). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics*, 363-374.

Latham, G. P. & Locke, E. A. (2007). New developments in and directions for goal-setting research. *European Psychologist,* 12, 290-300.

Lavrakas, P. J. (2008). *Encyclopedia of Survey Research Methods: AM*. Sage.

Lee, J. H., Kim, H. I. & Phaal, R. (2012). An analysis of factors improving technology roadmap credibility: A communications theory assessment of roadmapping processes. *Technological Forecasting and Social Change,* 79, 263-280. doi:10.1016/j.techfore.2011.05.003

Lee, S., Kang, S., Park, Y. & Park, Y. (2007). Technology roadmapping for R&D planning: The case of the Korean parts and materials industry. *Technovation,* 27, 433-445. doi:10.1016/j.technovation.2007.02.011

Lee, S., Lee, S., Seol, H. & Park, Y. (2008). Using patent information for designing new product and technology: keyword based technology roadmapping. *R & D Management,* 38, 169-188.

Lee, S. & Park, Y. (2005). Customization of technology roadmaps according to roadmapping purposes: Overall process and detailed modules. *Technological Forecasting and Social Change,* 72, 567-583. doi:10.1016/j.techfore.2004.11.006

Lee, S., Yoon, B., Lee, C. & Park, J. (2009). Business planning based on technological capabilities: Patent analysis for technology-driven roadmapping. *Technological Forecasting and Social Change,* 76, 769-786. doi:10.1016/j.techfore.2009.01.003

Lee, S. K., Mogi, G. & Kim, J. W. (2009). Energy technology roadmap for the next 10 years: The case of Korea. *Energy Policy,* 37, 588–596.

Lee, Y. E. (2005). R&D Strategy of the Korean Electric Industry Using a

Technology Roadmap(Trm) Approach. *Key Engineering Materials,* 277-279**,** 674-679.

Lewis, J. I. & Wiser, R. H. (2007). Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy,* 35**,** 1844-1857.

Li, G. (2011). Information science & technology in China a roadmap to 2050. Beijing : Science Press.

Li, J. S., Li, Y., Zeng, L., Hu, J. Y. & Muthu, S. S. (2010). Functional Materials Technology Roadmap for Guangdong Textile and Clothing Industry. *Textile Bioengineering and Informatics Symposium Proceedings* 2010.

Li, M. & Kameoka, A. (2003). Creating added value from roadmapping process: a knowledge-creating perspective. Paper presented at the Engineering Management Conference (IEMC '03). *Managing Technologically Driven Organizations: The Human Side of Innovation and Change*, 2003. 387-392.

Li, M. W., Li, Y., Zeng, L., Xue, F. P., Zou, C. L., Liu, Z. Q., Chen, Q. W., Yang, L., Liao, X. A. & Subramanian, K. (2010). Market Demand Analysis for Guangdong Textile and Clothing Industry. *Textile Bioengineering and Informatics Symposium Proceedings* 2010.

Li, S. N., Li, Y. & Cao, M. L. (2016). Current Status of the UK Textile Industry and its Sustainable Development. *In:* Li, Y. & Padhye, R., eds. *Textile Bioengineering and Informatics Symposium* 2016. 756-764.

Li, S. N., Li, Y. & Li, M. W. (2014). Analysis of Industrial Value Chains for Biomedical Textile Industry Technology Roadmap. *In:* Li, Y., Xin, J. H., Yoon, K. J. & Li, J. S. (eds.) *Textile Bioengineering and Informatics Symposium Proceedings 2014, Vols 1 and 2.*

Li, S. N., Li, Y., Li, M. W., Li, Z., Hu, J. Y., Guo, Y. P., Li, J. S., Li, G. & Cao,

M. L. (2013). Development of Technology Roadmap for Guangdong Biomedical Textile Industry. *In:* Li, Y., Yao, M., Gao, Y. & Li, J. S. (eds.) *Textile Bioengineering and Informatics Symposium Proceedings 2013, Vols 1-3.*

Li, S. N., Li, Y., Yao, M., Li, M. W., Li, Z. & Liao, X. (2012). Technology Platforms for Cluster Innovations in Biomedical Textile Industry. *In:* Li, Y., Takatera, M., Kajiwara, K. & Li, J. S. (eds.) *Textile Bioengineering and Informatics Symposium Proceedings 2012, Vols 1 and 2.*

Li, Y. & Xiong, X. Y. (2010). *Technology Roadmap of Textile and Clothing Industry-Guangdong Textile and Clothing Industry Technology Management Innovations*. Beijing: China Textile Press.

Li, Y., Xiong, X. Y., Zeng, L., Li, M. W., Liu, Z. Q., Yao, L., Wang, R. M., Hu, J. Y., Li, J. S. & Lv, R. (2010) Development of Technology Roadmap for Guangdong Textile and Clothing Industry. *Proceedings of Textile Bioengineering and Informatics Symposium* 2010.

Ling-Yee, L. & Ogunmokun, G. O. (2001). Effect of export financing resources and supply-chain skills on export competitive advantages: implications for superior export performance. *Journal of World Business,* 36**,** 260-279.

Lissack, M. R. (1998). Concept sampling: A new twist for content analysis. *Organizational Research Methods,* 1**,** 484-504.

Liu, C. (2012). Water science & technology in China a roadmap to 2050. Beijing : Science Press.

Lombard, M., Snyder-Duch, J. & Bracken, C. (2010). Intercoder reliability. *Retrieved February,* 3**,** 2011.

Lombard, M., Snyder - Duch, J. & Bracken, C. C. (2002). Content analysis in mass communication: Assessment and reporting of intercoder reliability. *Human Communication Research,* 28**,** 587-604.

Lu, K. (2010). Advanced materials science & technology in China : a roadmap to 2050. Beijing: Science Press.

Lucas Jr, R. E. (2003). Macroeconomic priorities. *The American Economic Review,* 93**,** 1.

Lv, R., Li, Y., Zeng, L., Liu, H. X. & Muthu, S. S. (2010). Dyeing and Finishing Technology Roadmap for Guangdong Textile and Clothing Industry. *Textile Bioengineering and Informatics Symposium Proceedings* 2010.

Madsen, J., Hartlin, B., Perumalpillai, S., Selby, S. and Aumônier, S. (2007). Mapping of evidence on sustainable development impacts that occur in the life cycles of clothing. *A Report to the Department for Environment, Food and Rural Affairs.* UK: Department for Environment, Food and Rural Affairs.

Mateik, D. (2010). From teaching technologies to teaching innovation: a conference changes with the times. *Proceedings of the 38th annual ACM SIGUCCS fall conference: navigation and discovery*. ACM, 29-32.

Mayberry, P. G. (2016). *U.S.* Export/Import Data Demonstrate Impacts of Globalization on the U.S. Nonwovens Industry. Nonwoven Industry. Retrieved from: http://www.nonwovens-industry.com/issues/2016-09/view_capitol-comments/us-exportimport-data-demonstrate-impacts-of-globalization-on-the-us-nonwovens-industry. [Accessed 27 May 2017].

Merges, R. P. (1988). Commercial success and patent standards: economic perspectives on innovation. *California Law Review***,** 803-876.

Miller, D. J., Fern, M. J. & Cardinal, L. B. (2007). The use of knowledge for technological innovation within diversified firms. *Academy of Management Journal,* 50**,** 307-325.

Mowery, D., Nelson, R., Sampat, B. & Ziedonis, A. (2015). *Ivory tower and industrial innovation: University-industry technology transfer before and after the Bayh-Dole Act*. Stanford University Press.

MSH (1995). *Rapid Pharmaceutical Management Assessment - an Indicatior-Based Approach*. Arlington.

Mwachofi, A. & Al-Assaf, A. F. (2011). Health care market deviations from the ideal market. *Sultan Qaboos University Medical Journal,* 11**,** 328-337.

Nabyla, D. (ed.) (2015). *Developing Strategic Business Models and Competitive Advantage in the Digital Sector.* Hershey, PA, USA: IGI Global.

NBSC. (2016). China statistical yearbook. Retrieved from: http://www.stats.gov.cn/tjsj/ndsj/2016/indexch.htm [Accessed 10 May 2017].

NBSC. (2017). Cotton production. National bureau of statistics of China. Retrieved from: http://data.stats.gov.cn/adv.htm?m=advquery&cn=C01 [Accessed 18 May 2017].

Neuendorf, K. A. (2016). *The content analysis guidebook*. Sage publications.

Nimmo, G. (2013). *Technology Roadmapping on the Industry Level: Experiences from Canada*. Springer Berlin Heidelberg.

OECD. (2017a). ANBERD: business enterprise R&D broken down by industry. Organisztion for Economic Co-operation and Development. Retrieved from: https://stats.oecd.org/Index.aspx?DataSetCode=STAN08BIS.[Accessed on 3 May 2017]

OECD. (2017b). STAN Bilateral Trade Database by Industry and End-use category. Organisztion for Economic Co-operation and Development. Retrieved from: https://stats.oecd.org/Index.aspx?DataSetCode=BTDIXE [Accessed 23 May 2017]. [Accessed on 3 May 2017]

OECD. (2017c). Trade in employment: core indicators. Organisztion for Economic Co-operation and Development. Retrieved from: https://stats.oecd.org/ [Accessed 10 May 2017]. [Accessed on 3 May 2017]

Oerlikon. (2010). Global Fiber Production Exceeded 70 Million Tonnes in 2009. Retrieved from https://www.oerlikon.com/ecomaXL/get_blob.php?name=The_Fiber_Year_2009_10_english.pdf. [Accessed on 3 May 2017]

Oi, W. Y. (1962). Labor as a quasi-fixed factor. *Journal of Political Economy,* 70**,** 538-555.

Panapanaan, V., Linnanen, L., Karvonen, M. M. & Phan, V. (2003). Roadmapping Corporate Social Responsibility in Finnish Companies. *Journal of Business Ethics,* 44**,** 133-148. doi:10.1023/A:1023391530903

Pataki, B., Szalkai, Z. & Biro-Szigeti, S. (2011). Some methodological issues of Technology roadmapping experienced during consultancy. *Perspectives of Innovations, Economics and Business, PIEB***,** 12-16.

Perkmann, M. & Walsh, K. (2007). University–industry relationships and open innovation: Towards a research agenda. *International Journal of Management Reviews,* 9**,** 259-280.

Phaal, B. Y. & Robert. (2013). Structuring technological information for technology roadmapping: data mining approach. *Technology Analysis & Strategic Management,* 25**,** 1119-1137.

Phaal, R. (2001). *T-plan: the fast start to technology roadmapping: planning your route to success*. Cambridge: University of Cambridge.

Phaal, R. (2010). *Roadmapping for Strategy and Innovation: Aligning Technology and Markets in a Dynamic World,* Cambridge. University of Cambridge, Institute for Manufacturing.

Phaal, R., Farrukh, C. & Probert, D. (2001a). *T-Plan : the Fast-Start to Technology Roadmapping : Planning Your Route to Success.* Cambridge, University of Cambridge, Institute for Manufacturing.

Phaal, R., Farrukh, C. & Probert, D. (2001b). *Technology Roadmapping: Linking Technology Resources to Business Objectives*. Centre for Technology Management, University of Cambridge**,** 1-18.

Phaal, R., Farrukh, C. & Probert, D. (2013). Technology Management and Roadmapping at the Firm Level. In M. G. Moehrle, R. Isenmann, & R. Phaal (Eds.), *Technology Roadmapping for Strategy and Innovation.* Springer Berlin Heidelberg.

Phaal, R., Farrukh, C. J., Mills, J. F. & Probert, D. R. (2003). Customizing the technology roadmapping approach. Paper presented at Portland International Conference on Management of Engineering and Technology (PICMET 03), 361-369.

Phaal, R., Farrukh, C. J. & Probert, D. R. (2005). Developing a technology roadmapping system. *Technology Management: A Unifying Discipline for Melting the Boundaries,* 31**,** 99-111.

Phaal, R., Farrukh, C. J. P. & Probert, D. R. (2001c). Fast-start technology roadmapping. Paper presented at Management of Technology: the Key to Prosperity in The Third Millennium. *Proceedings of the 9th International Conference on Management of Technology.* Miami FL: Pergamon.

Phaal, R., Farrukh, C. J. P. & Probert, D. R. (2004). Technology roadmapping—A planning framework for evolution and revolution. *Technological Forecasting and Social Change,* 71**,** 5-26. doi:10.1016/s0040-1625(03)00072-6

Phaal, R. & Muller, G. (2009). An architectural framework for roadmapping: Towards visual strategy. *Technological Forecasting and Social Change,* 76**,** 39-49. doi:10.1016/j.techfore.2008.03.018

Phaal, R., O'sullivan, E., Routley, M., Ford, S. & Probert, D. (2011). A framework for mapping industrial emergence. *Technological Forecasting and Social Change,* 78**,** 217-230. doi:10.1016/j.techfore.2010.06.018

Polit, D. F. & Beck, C. T. (2004). *Nursing research: Principles and methods*. Lippincott Williams & Wilkins.

Porter, M. E. (2008). *Competitive strategy: Techniques for analyzing industries and competitors.* Simon and Schuster.

Porter, M. E. & Millar, V. E. (1985). How information gives you competitive advantage. *Harvard Business Review*, Reprint Service Watertown, Massachusetts, USA.

Precision Consultancy Business & Council. (2007). *Graduate employability skills, Precision Consultancy.* Melbourne, Victoria.

Probert, D., Farrukh, C. J. & Phaal, R. (2003). Technology roadmapping—developing a practical approach for linking resources to strategic goals. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 217**,** 1183-1195.

Probert, D. & Shehabuddeen, N. (1999). Technology road mapping: The issues of managing technology change. *International Journal of Technology Management,* 17**,** 17.

Probert, D. R., Phaal, R. & Farrukh, C. J. P. (2000). Structuring a systematic approach to technology management: concepts and practice. *International Association for Management of Technology (IAMOT) Conference.* Lausanne.

Professional Academy. (2017). Marketing Theories – PESTEL Analysis. Retrieved from: http://www.professionalacademy.com/blogs-and-advice/marketing-theories---pestel-analysis. [Accessed on 3 May 2017].

Rip, A. & Kemp, R. (1998). *Tehcnological change*. Columbus, OH: Batelle Press.

Roberts, C. W. (1997). *Text analysis for the social sciences: Methods for drawing statistical inferences from texts and transcripts*. Lawrence Erlbaum Associates.

Robinson, D. K., Huang, L., Guo, Y. & Porter, A. L. (2013). Forecasting Innovation Pathways (FIP) for new and emerging science and technologies. *Technological Forecasting and Social Change,* 80**,** 267-285.

Robinson, H. S., Anumba, C. J., Carrillo, P. M. & Al‐Ghassani, A. M. (2006). STEPS: a knowledge management maturity roadmap for corporate sustainability. *Business Process Management Journal,* 12**,** 793-808.

Ronan, W. W., Latham, G. P. & Kinne, S. (1973). Effects of goal setting and supervision on worker behavior in an industrial situation. *Journal of Applied Psychology,* 58**,** 302.

Roper, S., Du, J. & Love, J. H. (2008). Modelling the innovation value chain. *Research policy,* 37**,** 961-977.

Ross, T. (1996). Indices for performance evaluation of predictive models in food microbiology. *Journal of Applied Bacteriology,* 81**,** 501-508.

Rosso, D. (2014). International Technology Roadmap for Semiconductors Explores Next 15 Years of Chip Technology. Retrieved from: https://www.semiconductors.org/clientuploads/Research_Technology/ITRS/2001/PIDS.pdf. [Accessed April 1 2014].

Rots, E. & Maduko, F. (2014). Macroeconomic Theory I. Retrieved from: https://ceulearning.ceu.edu/pluginfile.php/105956/course/overviewfiles/Macro%20I%20Syllabus.pdf?forcedownload=1. [Accessed 22 March 2017].

Sandelowski, M. (1995). Qualitative analysis: What it is and how to begin. *Research in nursing & health,* 18**,** 371-375.

Schoer, K., Weinzettel, J., Kovanda, J., Giegrich, J. R. & Lauwigi, C. (2012). Raw material consumption of the European Union–concept, calculation method, and results. *Environmental science & technology,* 46**,** 8903-8909.

Scifinder. (2017). CAS. Retrieved from: https://scifinder.cas.org/scifinder/view/scifinder/scifinderExplore.jsf. [Accessed 10 May 2017].

Scopus. (2017). Document search. Retrieved from: https://www.scopus.com/home.uri?zone=header&origin=searchbasic [Accessed 10 May 2017].

Semiconductor-Industry-Association. (1992). SIA Quarterly Quality Survey." Semiconductor Industry Association. *The National Technology Roadmap for Semiconductors: Technology Needs," SEMATECH, Inc*.

Smith, K. (2005). Measuring innovation. In: *The Oxford Handbook of Innovation*. New York, US: Oxford University Press, 148-177.

Statista. (2015). Cotton production in the U.S. from 2000 to 2015. The Statistics Portal. Retrieved from:

https://www.statista.com/statistics/191500/cotton-production-in-the-us-since-2000/ [Accessed 12 May 2017].

Statista. (2017). Global chemical fiber production from 2000 to 2015, by fiber type (in 1,000 metric tons). The statistics portal. Retrieved from: https://www.statista.com/statistics/271651/global-production-of-the-chemical-fiber-industry/ [Accessed 18 May 2017].

Stock, J. R. & Lambert, D. M. (2001). *Strategic logistics management*. McGraw-Hill/Irwin Boston, MA.

Suchman, M. C. (1995). Managing Legitimacy: Strategic and Institutional Approaches. *The Academy of Management Review,* 20**,** 571-610.

Sullivan, L. (2017). Nonparametric Tests. Boston University School of Public Health. Retrieved from http://sphweb.bumc.bu.edu/otlt/mph-modules/bs/bs704_nonparametric/bs704_nonparametric_print.html

Trading Economics. (2017). United States Average Hourly Wages in Manufacturing. Trading Economics. Retrieved from: http://www.tradingeconomics.com/united-states/wages-in-manufacturing [Accessed 10 May 2017].

Utterback, J. M. & Suárez, F. F. (1993). Innovation, competition, and industry structure. *Research Policy,* 22**,** 1-21.

Van Lamsweerde, A. (2004). Goal-oriented requirements enginering: a roundtrip from research to practice [enginering read engineering]. *Requirements Engineering Conference Proceeding*s, *12th IEEE International*, 4-7.

Vatananan, R. S. & Gerdsri, N. (2012). The Current State of Technology Roadmapping (Trm) Research and Practice. *International Journal of Innovation and Technology Management,* 09**,** 1250032. doi:10.1142/s0219877012500320

Vishnevskiy, K., Karasev, O. & Meissner, D. (2015). Integrated roadmaps and corporate foresight as tools of innovation management: The case of Russian companies. *Technological Forecasting and Social Change,* 90**,** 433-443.

Walsh, S. T., Boylan, R. L., Mcdermott, C. & Paulson, A. (2005). The semiconductor silicon industry roadmap: epochs driven by the dynamics between disruptive technologies and core competencies. *Technological Forecasting and Social Change,* 72**,** 213-236.

Wang, L., Wang, X. & Lin, T. (2010). 6 - Conductive coatings for textiles A2 - Smith, William C. *Smart Textile Coatings and Laminates.* Woodhead Publishing.

Wang, T. (2012). Advanced manufacturing technology in China a roadmap to 2050. Beijing : Science Press.

Wang, Z., Wei, S. J., Yu, X. & Zhu, K. (2017). *Characterizing Global Value Chains: Production Length and Upstreamness*. National Bureau of Economic Research.

Weber, R. P. (1990). *Basic content analysis*. Sage.

Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J. & Kanemoto, K. (2015). The material footprint of nations. *Proceedings of the National Academy of Sciences,* 112**,** 6271-6276.

Wilensky, H. L. (2015). *Organizational intelligence: Knowledge and policy in government and industry.* Quid Pro Books.

Willyard, C. H. (1987). Motorola's Technology Roadmap Process. *Research Management***,** 13-19.

Wimmer, M., Codagnone, C. & Janssen, M. (2008) Future e-Government Research: 13 Research Themes Identified in the eGovRTD2020 Project.

Paper presented at the 2014 47th Hawaii International Conference on System Sciences, 223-223.

Wimmer, M. A. (2007). Roadmap for future research and implementations in eGovernment: Reflecting the synthesis process of the roadmap themes. *In:* C. Codagnone & M. A. Wimmer (Eds.). *Roadmapping eGovernment Research: Visions and Measures towards Innovative Governments in 2020.* Clusone: MY Print snc di Guerinoni Marco & C.

Wimmer, M. A., Bicking, M., Bogataj, K., Bowern, M., C., C., Dawes, S. S., Janssen, M., Klein, M., Ma, X., E., M. & Pucihar, A. (2007). Roadmap for future research and implementations in eGovernment: Research themes and roadmap charts. *In:* C. Codagnone & M. A. Wimmer (Eds.), *Roadmapping eGovernment Research: Visions and Measures towards Innovative Governments in 2020.* Clusone: MY Print snc di Guerinoni Marco & C.

WITS. (2017a). Canada Textiles and Clothing Export. World Integrated Trade Solution. Retrieved from: http://wits.worldbank.org/CountryProfile/en/Country/CAN/StartYear/2006/EndYear/2010/TradeFlow/Export/Indicator/XPRT-TRD-VL/Partner/ALL/Product/50-63_TextCloth [Accessed 10 May 2017].

WITS. (2017b). Canada Textiles and Clothing Import. World Integrated Trade Solution Retrieved from: http://wits.worldbank.org/CountryProfile/en/Country/CAN/StartYear/2011/EndYear/2015/TradeFlow/Import/Indicator/MPRT-TRD-VL/Partner/ALL/Product/50-63_TextCloth [Accessed 10 May 2017].

WITS. 2017c. China Textiles and Clothing Export. World Integrated Trade Solution. Retrieved from: http://wits.worldbank.org/CountryProfile/en/Country/CHN/StartYear/2011/EndYear/2015/TradeFlow/Export/Indicator/XPRT-TRD-

VL/Partner/ALL/Product/50-63_TextCloth [Accessed 10 May 2017].

WITS. 2017d. China Textiles and Clothing Import. World Integrated Trade Solution. Retrieved from: http://wits.worldbank.org/CountryProfile/en/Country/CHN/StartYear/2011/EndYear/2015/TradeFlow/Import/Indicator/MPRT-TRD-VL/Partner/ALL/Product/50-63_TextCloth [Accessed 10 May 2017].

WITS. 2017e. United Kingdom Textiles and Clothing Export. World Integrated Trade Solution. Retrieved from: http://wits.worldbank.org/CountryProfile/en/Country/GBR/StartYear/2011/EndYear/2015/TradeFlow/Export/Indicator/XPRT-TRD-VL/Partner/ALL/Product/50-63_TextCloth [Accessed 10 May 2017].

WITS. 2017f. United Kingdom Textiles and Clothing Import. World Integrated Trade Solution. Retrieved from: http://wits.worldbank.org/CountryProfile/en/Country/GBR/StartYear/2006/EndYear/2010/TradeFlow/Import/Indicator/MPRT-TRD-VL/Partner/ALL/Product/50-63_TextCloth [Accessed 10 May 2017].

Woodrum, E. (1984). "Mainstreaming" content analysis in social science: Methodological advantages, obstacles, and solutions. *Social Science Research,* 13**,** 1-19.

Worldbank. (2017a). GDP growth (annual%). Retrieved from: http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=CN-CA-GB-US [Accessed 11 May 2017].

Worldbank. (2017b). Household final consumption expenditure. The World Bank Retrieved from: http://data.worldbank.org/indicator/NE.CON.PETC.ZS?locations=CN-CA-GB [Accessed 12 May 2017].

Worldbank. (2017c). Population growth. The World Bank. Retrieved from:

http://data.worldbank.org/indicator/SP.POP.GROW?locations=GB [Accessed 12 May 2017].

Worldbank. (2017d). Textiles and clothing (% of value added in manufacturing). The World Bank. Retrieved from: http://data.worldbank.org/indicator/NV.MNF.TXTL.ZS.UN?page=4 [Accessed 9 May 2017].

Xiang, J. (2010). Marine science & technology in China a roadmap to 2050. Beijing : Science Press.

Xiong, X. Y., Li, Y., Zeng, L., Liu, Z. Q., Liu, S., Liu, H. X., Xiang, W. B., Wang, J. J., Li, M. W., Liao, X. A. & Subramanian, K. (2010). *Research Needs for Guangdong Textile and Clothing Industry*. *Proceedings of Textile Bioengineering and Informatics Symposium* 2010.

Yao, L., Li, Y., Xiong, X. Y., Zeng, L. & Liu, Z. Q. (2010a). *Infrastructure Development Roadmap for Guangdong Textile and Clothing Industry*. *Proceedings of Textile Bioengineering and Informatics Symposium* 2010.

Yao, L., Li, Y., Zeng, L., Xiang, J. Y. & Muthu, S. S. (2010b). *Product Design Innovation Technology Roadmap for Guangdong Textile and Clothing Industry*. *Proceedings of Textile Bioengineering and Informatics Symposium* 2010.

Yasunaga, Y., Watanabe, M. & Korenaga, M. (2009). Application of technology roadmaps to governmental innovation policy for promoting technology convergence. *Technological Forecasting and Social Change,* 76**,** 61-79. doi:10.1016/j.techfore.2008.06.004

Yixin, L. (2011). On the connotation and evaluation of original innovation. *Energy Procedia,* 5**,** 643-646.

Yoon, B., Phaal, R. & Probert, D. (2008). Morphology analysis for technology roadmapping: application of text mining. *R&D Management,* 38**,** 18.

Zeng, L., Tang, Y. L. & Li, C. D. (2014). *Industry technology roadmap: to explore a route to cultivate strategical and innovative industry*. Beijing: *Science Publication*.

Zhao, J. (2010). Ecological and environmental science & technology in China a roadmap to 2050. Beijing : Science Press.