

Technology Mapping: Definitions, Types, and Applications

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Abstract

The literature of technology mapping or Roadmapping, as a one of the elements used in technology management, reviewed in this research to understand how technology mapping has been developed, define technology mapping, identify the types, and applications of technology mapping. This has been done by analyzing the various studies in technology mapping. It has been proved in this research that technology mapping went through three different phases namely product technology Roadmapping, emerging technology Roadmapping, and innovations Roadmapping. Technology mapping or technology Roadmapping both terminologies used to describe the methods used in generating technology roadmaps to support decision-making process and organization strategic planning. Three types of Technology Roadmapping identified in this research namely “based on purpose”, “based on format”, and “based on use”. For applications, three applications only identified in the current research namely Sustainable new product development decisions, Fuel cell sub-technologies’ identification, and Foresight studies. However, it was stated in the literature that technology mapping could be applied and used in different fields. The analysis conducted on the technology Roadmapping literature highlighted many challenges and feature research directions which we discussed in this research.

Keywords

Technology; Management; Mapping; Roadmapping.

1. Introduction

Technology can be defined as “the application of scientific knowledge for practical purposes, especially in industry” (Prima, Oktaviani and Sholihin, 2018). It was stated in the literature that scientists usually generate the new knowledge and then the technologists apply it and it was assumed that engineering covered all technologies. Therefore, technology can be viewed as a field that involves ideas and techniques and, on the other side, things that exist because of designs (Layton, 1974). In fact, it was stated in the literature that “technology” has two dimensions, the first one is knowledge about the man-made world and the second is the community of people that includes engineers, scientists, inventors and craftsmen that participate in the creation of knowledge (Wise, 1985). Management can be defined as a set of activities and principles used for administration of an organization (Fabus, Kremenova and Fabusova, 2017). Hence, technology management can be defined as a “set of management disciplines that allows organizations to manage their technological fundamentals to create competitive advantage” (Chen, Huang and Chen, 2012). It was stated in the reviewed literature that “technology management addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies” and is required for maintaining a place in the market and meeting with the company’s objectives (Phaal, Farrukh and Probert, 2004). One of the important issue in the technology management discipline is maintaining effective linkage between technological resources and the company’s objectives, however, it is still one of the big companies’ challenges. To support this, communication and

management of knowledge are required. Moreover, using the right tools and the right management processes is mandatory (Phaal, Farrukh and Probert, 2004). Technology mapping or Roadmapping is one of the effective tools that visualize and communicate required messages to company management regarding current patterns of technology (Carvalho, Fleury and Lopes, 2013). The main objectives of this research are understanding how technology mapping has been developed, define technology mapping, and identify the types and applications of technology mapping. After introduction, paper will follow the following structure; in the second section, research methodology will be discussed. In the third section, literature review will be conducted. In the fourth section, literature review results will have analyzed in order to draw conclusions which will be presented in the last section.

2. Methodology

In order to study and analyze technology mapping, the methodology used in this research encompasses four steps. In the first step, a search for publications will be conducted on the Google Scholar and Science Direct databases using the search terms “Technology”, “Management”, “Mapping”, and “Roadmapping”. In the second step, papers’ abstract will be reviewed to select only papers on the scope of current research, i.e. technology mapping. The Selected papers that covers the research concept will be reviewed in the third step. In the last step, the analysis, limitations, conclusions and future of technology mapping will be conducted based on the literature review results.

3. Technology Mapping Literature Review

This section will cover the different definitions of technology mapping that were discussed in the literature review. After that the technology mapping development will be addressed, followed by types and methods of technology mapping. At the end, several applications that used technology mapping will be highlighted. Based on the literature review, technology mapping has been considered as a tool for technology management. Technology mapping is a concept that combines innovation and communication in the technology management field. de Alcantara and Martens (2019) did a systematic review of the literature focusing on models in technology Roadmapping and mentioned that this approach is applied in different organizations to achieve effective strategic objectives with technology. Phaal, Farrukh and Probert (2004) state that technology mapping is used to support strategic decisions and long-range planning. In addition, it provides a way for companies to explore the future and to scan the environment and also a method in which companies can track the performance of individuals. According to Phaal, Farrukh and Probert (2004) the use of technology mapping can be categorized based on two major purposes which are; a company perspective in which technology roadmaps “allow technology developments to be integrated with business planning and the impact of new technologies and market developments to be assessed”. Other perspective is multi-organizational, in which capturing the environmental landscapes and looking at threats and opportunities for certain stakeholders or for a certain technology or field is implemented. Phaal, Farrukh and Probert (2004) mentioned that the goal of technology mapping is supporting the development and implementation of integrated strategic business, product and technology plans, assuming that the companies or organizations applying technology mapping are capable and have enough information and supportive tools.

Phaal, Farrukh and Probert (2006) studied the technology management tools in terms of concept, development and application and helps in understating how the Roadmapping supports the integrated strategic planning at the firm and sector levels. At the beginning, Phaal, Farrukh and Probert (2006) defined the management tools as a framework, process, document, system or method that allows the company to achieve their goal and objective. In addition, the forms of tools can be matrices, grids, tables, graphs, checklists, lists and software. After that, they discussed the matrix management tools which have different types such as matrix, grid, table and scored profile. The most common type of tool is the classic matrix (2x2) which is used by consultants, managers and academics. It is considered simple in terms of concept and application, supporting communication, and is flexible. Phaal, Farrukh and Probert (2006) added that many practical problems or concerns cannot be simplified to only two dimension. Finally, Phaal, Farrukh and Probert (2006) developed a tool catalogue that is useful for industry and improving the understanding of the purpose of tools. The structure of this was implemented with 11 groups which were: Technology Management, Innovation Management, Knowledge Management, New Product/Service and Process Development, Business Strategy, Management/Business, Marketing and Customers, Behavior, Culture and Human Resources, Organization and Collaboration, Change Management, Planning and Projects and finally General Problem Solving. The management tool catalogue developed in this research used to provide a resource for supporting the Roadmapping process which comes under development and application of management tools. The authors mentioned that in integrated strategic

planning they use technology Roadmapping at the firm and sector levels which incorporate technical and commercial aspects clearly. In Figure (1) below readers can see the most common format which is known as the graphical framework and shows how technology and product developments associated with business and markets goes through the function of time. In addition, it provides a useful integrating mechanism for company strategy and planning activities.

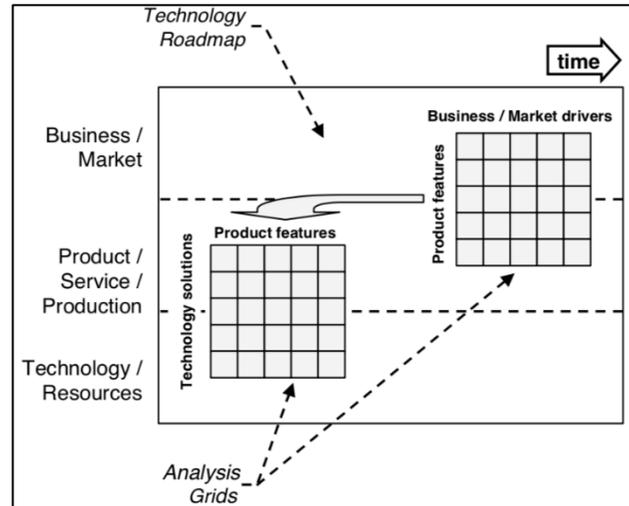


Figure 1. Layers of the technology roadmap (Phaal, Farrukh and Probert, 2006)

According to Phaal and Palmer (2010) mapping is essential due to the challenges of the different educational backgrounds and expectations in the organization. Based on Phaal and Palmer (2010) “roadmaps can be thought of as strategic “lenses” through which individuals and groups of stakeholders can view an area of common interest. This might be a technology, product, or business”. Based on Carvalho, Fleury and Lopes (2013) the Roadmapping approach was developed by Motorola considering the period from 2000 to 2013, technology Roadmapping went through three different phases which can be seen as generations. The first generation of technology Roadmapping focuses on the product technology roadmap. The second generation is the one focusing on emerging technology Roadmapping, while the third generation of technology Roadmapping is the one that puts an emphasis on the innovation roadmaps. In addition, the authors mentioned that all the three generations were developed as a result of innovation (Carvalho, Fleury and Lopes, 2013).

3.1. Types of Technology Mapping

Technology mapping were divided into three forms/types which are based on purpose, based on format and based on use. Phaal, Farrukh and Probert (2004) mentioned that the roots of roadmaps started in the 1970s. Furthermore, technology maps can be shown in different forms. Those forms depend on the purpose of the roadmap. The most common one is the time-based chart which mostly includes commercial and technological perspectives, along with the linkages of any other related perspectives. Due to the fact that technology mapping is closely related to planning, many other approaches are also related to technology Roadmapping such as technology forecasting, foresight futures, Delphi, and scenario planning. Phaal, Farrukh and Probert (2004) explored eight types of technology roadmaps as shown in Figure (2), and elaborated that the benefit of technology roadmaps is to have a time-based structured framework to develop, show and communicate strategic plans. Based on Phaal, Farrukh and Probert (2004), the types of technology roadmaps based on purpose can be categorized to:

1. Product planning: relating technology to product development.
2. Service/capability planning: it focuses on how technology supports organizational capabilities.
3. Strategic planning: examines both opportunities and threats and works on a vision of the future.
4. Long-range planning: support long-range planning.
5. Knowledge asset planning: “aligns knowledge assets and knowledge management initiatives with business objectives” (Phaal, Farrukh and Probert, 2004).
6. Program planning: related to implementation of strategy and to project planning.

7. Process planning: supports the management of knowledge, while concentrating on a certain process area.
8. Integration planning: focuses on integration and/or evolution of technology, in the aspect of how “different technologies combine within products and systems (Phaal, Farrukh and Probert, 2004).

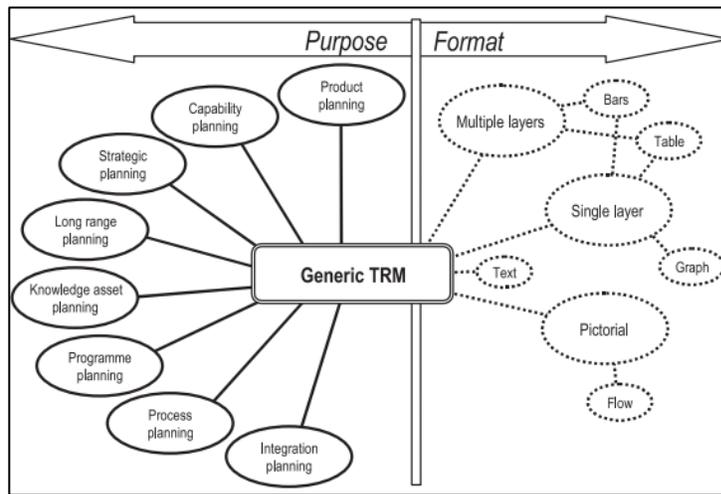


Figure 2. Examples of technology roadmaps type based on purpose (Phaal, Farrukh and Probert, 2004)

Phaal, Farrukh and Probert (2004) mentioned that different formats have been identified in regard to technology mapping. According to Phaal, Farrukh and Probert (2004) there are eight types of graphical formats: multiple layers, bars, tabular, graphical, pictorial, and flow chart as shown below in Figure (3) along with text and signal layer. de Alcantara and Martens (2019) mentioned the other type of technology mapping which is technology mapping based on usage. “based on usage” were mentioned in a study done by Oliveira and Rozenfeld (2010) whom showed the complementary characteristics between technology Roadmapping and project portfolio management. This method is used in supporting the initial phase of the process of new product development (de Alcantara and Martens, 2019). In addition, based on Tuominen and Ahlqvist (2010) and in the context of transport systems analysis, it was explained that technology Roadmapping considers social and technical “combinations of layers of the roadmap related to science and technology” in which there exist five layers which are: user needs, markets, actors, technologies and assessment knowledge (Tuominen and Ahlqvist, 2010).

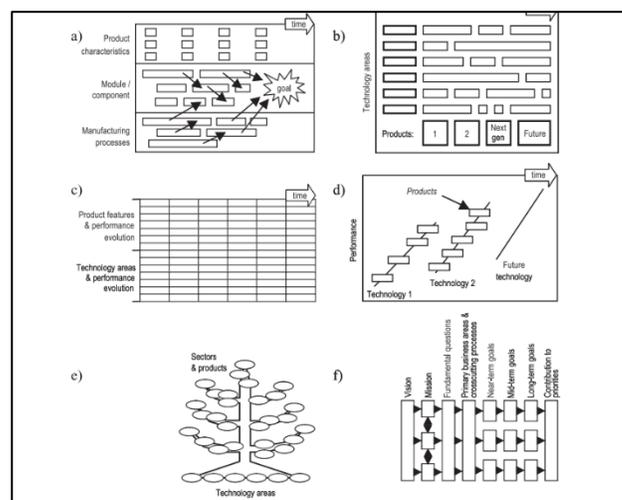


Figure 3. Examples of technology roadmaps type based on format (Phaal, Farrukh and Probert, 2004)

3.2. Technology Mapping Applications

Several applications were introduced in the literature review, the points below highlight three different types of applications:

A. Sustainable new product development decisions

Petrick and Echols (2004) explained how supply chain management could be used by combining it with the IT results in a technology Roadmapping tool, which will help managers to make decisions on new product development. The study started with an overview of the technology development and innovation theory and mentioned that the choices taken which consider long-term expectations as well the evolution of technology of any new product developments are significant for the future success of firms, and that this should be done instead of focusing on short-term returns. In addition, the authors explained why the firms must use technology roadmaps in choosing an innovation strategy because it is an aid in managing innovation. Moreover, the roadmap is used for identifying the technologies for both current and planned products as well as showing the accepted technology developments along with the required elements to plan for a successful new product development.

B. Fuel cell sub-technologies' identification

Arasti and Bagheri Moghaddam (2010) used technology mapping in the identification of fuel cell sub-technologies. In this research the authors discussed the characteristics of four methods of Technology Identification, which are Value Chain of Technologies, Process-based Approach, Quality Function Deployment and Technology Mapping in order to identify the most appropriate method to be used for the fuel cell sub-technologies. Figure (4) below represent a comparison of the four methods of technology identification. Value Chain of Technologies, this method is an appropriate concept to help identify the process technologies at company level through the development of the firm's value chain, identification of current technologies and identification of new technologies. Process-based approach, this method is appropriate for identifying process technologies of a company or an industry and the process is defined as a set of activities that convert inputs into outputs to produce a valued result for both internal and external customers. Quality Function Deployment (QFD), this method is appropriate for identifying product as well as process technologies based on customers' requirements and it involves utilizing the attributes of a product or service preferred by customers. The following three steps are essential in using the QFD method, (1) Converting customer requirements into quality characteristics, (2) Relating the quality characteristics to product or service attributes, (3) Identifying technologies that will be used in the company's products or services. Technology mapping, This method is a suitable method for identifying technologies when facing with an area or a sector, not referring to a specific firm as well as not referring to a specific product or service with certain customers. Based on the comparison above, Arasti and Bagheri Moghaddam (2010) selected the technology mapping because of the following features:

- There is no any specific company or product or production processes addressed.
- The fuel cell is a type of technology that includes a varied range of sub-technologies.

- A simple identification (list-up) was applicable for the technology mapping.

Scope \ Target	Identification (Simple List-Up)	Identification & Pre-Evaluation (Screening)
Product Technologies	Techno. Mapping	QFD
Process Technologies	Porter's Value Chain	Process-Based Approach
Area Technologies	Techno. Mapping	

Figure 4. Comparison of the four methods of technology identification (Arasti and Bagheri Moghaddam, 2010)

C. Foresight studies

Gudanowska (2016) introduced new methodology of technology mapping which will be used in Foresight studies. As shown in Figure (5), the methodology consists of four phases and each phase includes some tasks to accomplish. Some of the tasks must be performed in sequence while others can be conducted simultaneously. However, as shown in Figure (5), the concept phase, which is the first phase to start by, was recognition and identification of characteristics and data gathering tools. The second phase is the collection of knowledge which included gathering and identifying all data that has been selected in the concept phase. Moreover, visualization and presentation of the knowledge phase concerns the preparation of technology cards, maps and comparative visualizations. Finally, the conclusion phase was where all the information gathered was prepared for analysis. In addition, the author mentioned that when the technology mapping method is performed widely, it should include elements of the two approaches but with a suitable explanation for the recipients of the method's effects; the annotation will then enable them to make adequate conclusions.

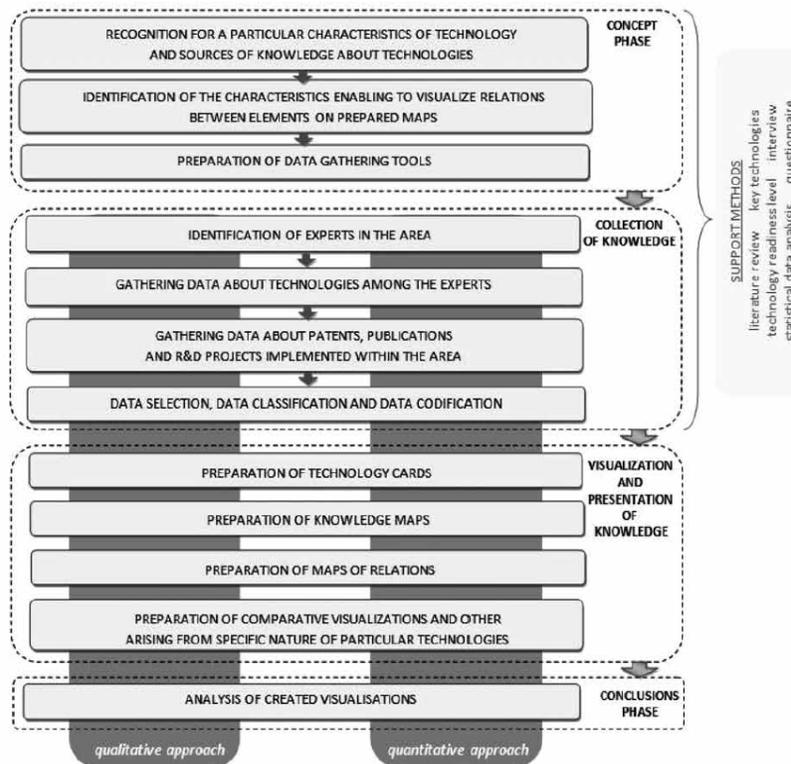


Figure 5. technology mapping methodology (Gudanowska, 2016)

4. Results Discussion

It has been proved in this literature review that technology mapping or technology Roadmapping both terminologies used to describe the methods used in generating technology roadmaps to support decision making process and organization strategic planning (Phaal, Farrukh and Probert, 2004). Phaal, Farrukh and Probert (2006) confirmed that technology mapping supports the integrated strategic planning at the firm and sector levels. Phaal, Farrukh and Probert (2004) has categorized technology mapping into two different perspectives, which were company and multi-organizational perspectives. In the development of technology mapping, Carvalho, Fleury and Lopes (2013) emphasized that the communication that occurs during the creation of the roadmaps is considered more important than creating the roadmap itself. Literature review analysis showed that technology Roadmapping went through three different phases, which can be seen as generations. The first generation of technology Roadmapping focuses on the product technology roadmap. The second generation is the one focusing on emerging technology Roadmapping, while the third generation of technology Roadmapping is the one that puts an emphasis on the innovation roadmaps (Carvalho, Fleury and Lopes, 2013). Phaal, Farrukh and Probert (2004) introduced three types of technology mapping but they elaborated it into two types, which were technology mapping based on purpose and technology mapping based on format. In addition, technology mapping based on use was not as widely discussed by Phaal, Farrukh and Probert (2004) as it was with de Alcantara and Martens (2019).

For technology mapping applications, three applications identified in this research. Petrick and Echols (2004) introduced the use of the technology Roadmapping tool for making sustainable new product development decisions and explained why firms must use technology roadmaps to choose an innovation strategy. Arasti and Bagheri Moghaddam (2010) used technology mapping in the identification of fuel cell sub-technologies by comparing four methods of technology management identification. And Gudanowska (2016) used technology mapping method in foresight studies. However, it was stated in the literature that technology mapping can be applied and used in different fields (Phaal, Farrukh and Probert, 2004; Arasti and Bagheri Moghaddam, 2010; Gudanowska, 2016). Based on the literature review, one of the challenges mentioned by de Alcantara and Martens (2019) was “keeping the roadmap alive”. This highlights the need to update the information in the roadmap on a continuous basis. In addition, it was

mentioned that technology Roadmapping is not a mature concept and is in an exploratory phase of research. Furthermore, the relationship between technology mapping and other initiatives in the organization is in a blur phase, those initiatives include knowledge management and communication skills, which are somehow related to technology mapping. Although companies have shown more interest recently in the concept of technology mapping, there is lack of papers related to technology mapping. However, publications have started increasing since 2004 (Carvalho, Fleury and Lopes, 2013). In addition, there is a lack of documentation when it comes to the best methodologies of technology mapping and the tools and practices related to it. Moreover, Carvalho, Fleury and Lopes (2013) mentioned that in the literature review there is a lack of addressing the relationship between technology Roadmapping and other initiatives such as innovation and corporate strategy. Actually, companies struggle in applying technology Roadmapping because there are many forms of roadmaps available (Phaal, Farrukh and Probert, 2004).

5. Conclusion and Future Research

Technology mapping or Roadmapping is a tool that combines innovation and communication in the technology management field. Technology mapping applied in different organizations to achieve effective strategic objectives with technology, to support strategic decisions, for long-range planning, provides a way for companies to explore the future, scan the environment and to track the individuals' performance. It has been proved in the literature review that technology mapping went through three different phases, which can be seen as generations: the first generation of technology Roadmapping focuses on the product technology roadmap, the second generation is the one focusing on emerging technology Roadmapping, while the third generation of technology Roadmapping is the one that puts an emphasis on the innovation roadmaps. It has been proved in this literature review that technology mapping or technology Roadmapping both terminologies used to describe the methods used in generating technology roadmaps. Literature review showed as well technology Roadmapping methodologies or tools can be categorized to three types, which are based on purpose, based on format and based on use. Regarding the applications of technology mapping, researchers in the current research were able to identify three applications only. However, it was stated in the literature that technology mapping could be applied and used in different fields. Literature review showed a struggle in implementing technology Roadmapping, only 10% of large organizations have implemented it (Phaal, et al., 2004). The reasons vary from the confusion of which form the company should use, to the fact that there is not enough practical support and knowledge sharing in this field. Furthermore, when it comes to the best methodologies of Roadmapping there is a lack of documentation, lack of tools and practices, and there is a lack of addressing the relationship between technology Roadmapping and other initiatives. It has been proved in the literature that having more primary information would have been helpful in terms of understanding the different concepts and methods by relating them to practical-life situations. We can conclude that technology mapping carries significant scope for future researchers, as it would enable them to think of the elements to be reconsidered in the future. Based on the literature review, it can be seen that technology mapping can provide a competitive advantage to organizations but those organizations need to pay attention to the importance of innovation and communication within the organization itself. Technology mapping can be considered as a planning tool and it is a method in which organizations can improve. Implementing technology mapping is not the ultimate solution; rather organizations should keep the map alive by updating it and adding more criteria, fields and tools to it throughout the years.

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