Technological Forecasting & Social Change 80 (2013) 1418–1437

Contents lists available at SciVerse ScienceDirect

Technological Forecasting & Social Change

An overview of the literature on technology roadmapping (TRM): Contributions and trends

M.M. Carvalho [1], André Fleury [1], Ana Paula Lopes *

Department of Production Engineering, University of Sao Paulo, Av. Prof. Almeida Prado, 05508-070 Sao Paulo, Brazil

ARTICLE INFO

Article history:
Received 27 September 2012
Received in revised form 19 November 2012
Accepted 21 November 2012
Available online 4 February 2013

Keywords:
Technology roadmapping
Roadmap
Roadmapping
Bibliometric study

ABSTRACT

In recent years, technological advances have motivated industries, companies and even governments to look for an improved alignment between strategic objectives and technology management, preferably through the application of structured and flexible approaches that use techniques such as technology roadmapping. This paper presents the outcomes of a systematic review of the literature relating to technology roadmapping that was published between 1997 and 2011. A hybrid methodological approach that combines bibliometrics, content analysis and semantic analysis was applied. The results show that the main academic journals that discuss this theme are "Technology Forecasting and Social Change" and "Research-Technology Management". Although the first paper relating to this theme was published in 1997, the number of publications on the subject only began to increase substantially in 2004. Most of the studies reviewed in this paper applied qualitative research methods, indicating that most of the research on the theme is still in an exploratory phase. The interface between roadmapping and other initiatives considered vital to innovation, including knowledge management, communication skills and strategic resources and competencies, are also poorly addressed in the reviewed literature.

1. Introduction

Technological change and globalization impact organizational structures and increase competition among companies and countries and thereby bring technology and innovation management to the center of corporate decision-making processes. It has become increasingly necessary for companies to understand the relationships between technological capabilities and corporate objectives [1,2]. Decisions that do not incorporate technological considerations for the development of innovations are unsustainable.

The roadmapping approach was developed at Motorola to improve the alignment between technology and innovation [3]. Its application became popular during the last decade and it was adopted by companies, governments and other institutions [4]. The roadmapping approach includes two main components, namely the application (i.e., the roadmapping process) and the result of the application (usually a map known as the roadmap). Therefore, the word "roadmap" represents a summary of science and technology plans in the form of maps, and the roadmapping process is the development of this roadmap [5]. Although a roadmap can be presented in several forms, it usually includes a multilayer graphical representation of a plan that connects technology and products with market opportunities (See Fig. 1) [1,2].

The time perspective considered in this analysis depends on the type of industry and its planning horizon [1]. The dialog and communication that occur during the roadmapping process are usually more important outcomes for the organization than the final roadmap itself [6]. Roadmapping is more likely to succeed in situations where threats have been previously identified [7].

The number of academic publications relating to roadmapping has increased during the last few years [4] because companies have augmented their interest in the application of roadmapping and researchers have documented the results of these initiatives, usually in the form of case studies. However, a more detailed analysis of the academic publications relating to

* Corresponding author. Tel.: +55 11 30915363; fax: +55 11 30915399.
E-mail address: aplopes10@hotmail.com (A.P. Lopes).
[1] Tel.: +55 11 30915363; fax: +55 11 30915399.

0040-1625/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.techfore.2012.11.008

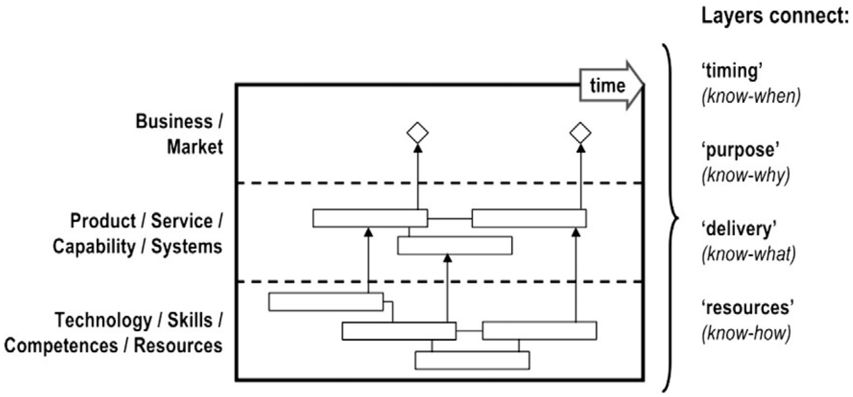

Fig. 1. Generalized technology roadmap architecture. Adapted from Probert et al. (2003).

roadmapping reveals some knowledge gaps. There is, for example, a lack of research that documents the main contributions of this approach and that synthesizes its main constructs, the most important methodologies, and the associated tools and practices.

This paper presents the outcomes of a literature review relating to technology roadmapping and its evolution over time. It summarizes and consolidates the existing body of knowledge relating to this theme to identify directions for future research initiatives. The methodological approach adopted for this is a systematic literature review that combined the techniques associated with bibliometrics, content analysis and semantic analysis.

The paper is structured in five sections. Section 1 presents the research, its context and its objectives. Section 2 presents the methodological approach. Section 3 presents the results that were obtained. Section 4 presents a discussion about the findings, and Section 5 presents the most important conclusions and contributions of the research.

2. Research methods

The systematic review in this study of the existing literature relating to technology roadmapping aims to comprehensively identify and synthesize research on a particular theme by applying structured, transparent and replicable procedures for every phase of the process [8].

There are different possibilities that can be considered in developing a literature review, including a bibliometric approach [9–11], meta-analysis [12] and content analysis [13]. The increasing growth of academic research and publications stimulated interest in bibliometric studies and a recognition that such studies are relevant [14]. These studies focus primarily on the identification of patterns of literature based on an analysis of publications [10]. They also focus on the identification of the most important academic works and authors based on an analysis of citations [11].

A bibliometric study can include content analysis and thereby allow the identification of the most important topics, approaches and methods, as well as the most important definitions of a theme [13,15]. It is possible to complement a bibliometric study by using semantic analysis, which captures information to quantify sequences of words, modeling a related language [16]. Semantic analysis can use manual or semiautomatic approaches [17]. Fig. 1 presents the phases of the literature review conducted in this study.

2.1. Sample and procedures

To obtain the initial sample a database was selected and it was searched with no restrictions relating to academic disciplines, journals or publication dates. The ISI Web of Science database was selected for this process because a search of this database includes papers from other databases (such as Scopus, ProQuest and Wiley) that were published in indexed journals with a calculated impact factor in the JCR (Journal Citation Report). Moreover, the ISI Web of Science database provides a set of metadata that is essential for the bibliometric analysis, including abstracts, references, number of citations, list of authors, institutions, countries and the journal impact factor.

The keywords used for the database search were "technology roadmapping" or "technology-roadmapping" or "roadmapping." Only peer-reviewed papers containing the previously mentioned metadata were considered. The initial search resulted in the identification of 100 papers from the ISI Web of Science database that had been published in 47 journals, and it identified 270 authors who had participated in the development of the 100 papers. The papers were classified under 35 thematic areas, and they had all been published in the years from 1997 (the first occurrence) until 2011. After the abstracts were read, 21 papers were excluded from the sample. The papers that were excluded contained at least one of the search keywords but they did not directly address the topic "technology roadmapping". The researchers read the abstracts of all the initially identified papers separately and only excluded from the sample those papers that they both agreed did not meet the criteria for inclusion (Fig. 2).

After the papers that did not meet the criteria had been excluded, the sample included 79 selected papers. Applying the snowball method [18,19], this initial sample was expanded to incorporate other papers that had been cited in the 79 papers. The total number of references cited in the papers from the initial sample was 1431. At this stage, other types of papers (including books) were incorporated into the database. The criterion for the inclusion of additional papers that had been cited in papers from the initial sample was a quote in the paper from the initial sample, as explained in the section on the bibliometric analysis.

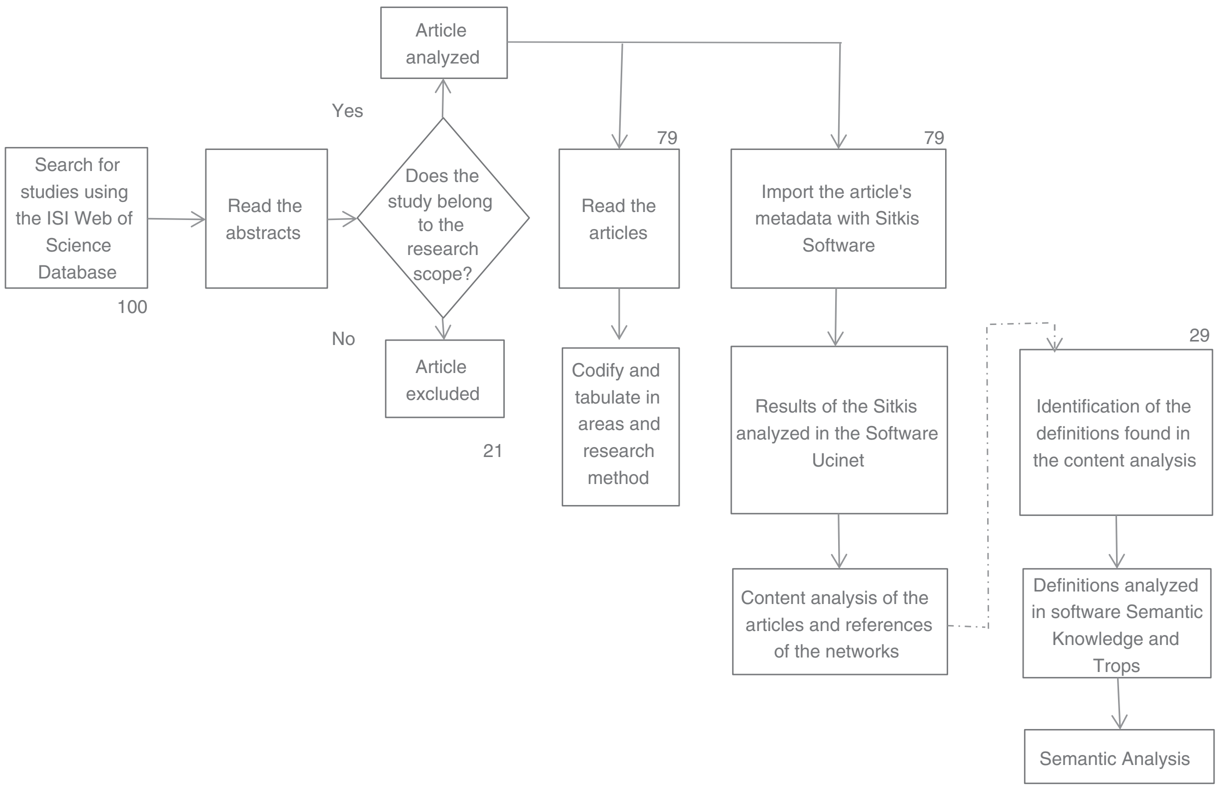

Fig. 2. Workflow of the literature review.

2.2. Bibliometric analysis

The first bibliometric indicator was the number of publications stratified by journal and year. This analysis made it possible to identify journals that often addressed the theme and to examine the way the publications evolved over time.

In the next phase, changes in the number of publications that addressed the theme were analyzed by year, considering the level of analysis and the methodological approach that was applied. The classification of papers according to the level of analysis was based on an analysis of the keywords, grouped by an affinity diagram, resulting in three levels of analysis. An adapted codification scheme was used to classify the papers according to the methodological approach that was used [20,21]. Table 1 shows the codification scheme that was used to classify the papers. The results are presented in Appendix I.

A list of the most frequently cited papers was created because these are the papers that influenced the research of the greatest number of authors [15,22,23]. The most cited papers, and the references that were cited most frequently in these papers, were analyzed to develop four networks of citations: keywords, article to references, co-citations and cross-citations.

The citation analysis was conducted using several software programs including Sitkis 2.0 [24], Ucinet for Windows 6.289 [25] and NetDraw [25]. Sitkis made it possible to import metadata from the scientific database. Ucinet and NetDraw were used to develop the networks, to conduct statistical analysis, and to analyze indicators of centrality and betweenness.

The first citation network that was developed in this study was the most frequently cited keywords network. The second network that was developed was the citations of papers for references network. This network connected the most cited papers from the initial sample with the most cited references from these papers. At this stage of research, papers from other databases that are not indexed in the ISI Web of Science, and other types of references such as books and conference papers, were incorporated into the analysis because they are frequently mentioned in the papers of the initial sample.

The third network that was designed was a co-citation network that indicates the degree of similarity among references by showing the papers that have been mentioned together. An analysis of this network can help in understanding the intellectual structure of an area and to map the

Table 1
Codification of the research method and level of analysis.

Research method	Level of analysis
Conceptual research	LA1-Strategy & business level
CR1: Literature review	LA2-Innovation-science & technology level
CR2: Simulation or theoretical modeling	LA3-New product development level
Empirical research	
ER1: Survey	
ER2: Case study	
ER3: Action research	

thematic affinities of researchers and the way groups of researchers relate to each other [22,23,26].

Finally, a cross-citation network was developed to show the papers that were mutually cited. This network makes it possible to identify possible clusters of authors, and it reveals the self-citation mechanisms. As a criterion for the development of the networks, references that were cited in a range from 1 to 10% of the sample were included pursuant to the suggestion in the Sitkis user's guide [24]. For this network, centrality and betweenness indicators were calculated.

2.3. Content and semantic analysis

Each paper included in the sample was registered individually using Mendeley software and a Microsoft Access file that contained the metadata generated by Sitkis software. For the content analysis, papers were classified in a way that considered the complementary tools that were applied, the scope of application, the relevant industrial sectors, the innovation goals, the size of the company, the advantages and limitations of the roadmapping process, the phases of roadmapping that were conducted, and the conditions that were necessary to obtain good results using the roadmapping procedures.

The next research activity involved conducting a semantic analysis. In this procedure, the most frequently cited papers and the most important references found in their networks of citations were analyzed, aiming to identify definitions of the key themes, specifically "roadmap", "roadmapping" and "technology roadmapping" (see Appendix II). The definitions were analyzed using manual and semi-automatic approaches [17]. In this study the Semantic Knowledge support software and Tropes software were also used. The semantic analysis phase of this research involved an analysis of the syntactic structures and the context of the text in the semantic-sample space that contained definitions of the studied terms (i.e., "TRM", "roadmapping" and "roadmap").

The purpose of the analysis of the definitions was to identify the differences among the three terms and to characterize the different perspectives invoked by the definitions of the terms. The most common relationships among the terms in the definitions made the elaboration of a definition synthesis possible. The detailed analysis of the definitions that were presented in the papers was used to propose a new definition for the three terms. To perform this semantic analysis, the researchers conducted three group dynamics. Each dynamic used visual display techniques, affinity diagram analysis, and Tropes Semantic Knowledge software support, and lasted for three hours.

Semantic Knowledge software was used to prepare a quantitative description of the main verbs, adjectives and nouns and to quantify the most frequent relationships between words. Tropes software was used to generate graphical analyses depicting graph area, graph actors and graph stars. In the graph area results, each reference appears as a sphere with a surface area that is proportional to the number of words it contains. The distances between the central class and the other classes are proportional to the number of relationships that connect the classes. The actors graph results show the concentration of relationships between the main actors (actant/acted). The star graph results display the relationships between references, or between a word category and a reference.

3. Results

This section considers the evolution of the number of publications and year (See Table 2).

The first paper relating to roadmapping was published in 1997 but the number of research papers relating to this area only started to increase in 2004. Approximately 50% of all the papers (40 of 79) relating to roadmapping was published in just two journals: "Technological Forecasting and Social Change" and "Research-Technology Management".

Table 3 presents the evolving trends in publications classified by level of analysis and methodological approach in three five-year periods: Q1: 1997 to 2001; Q2: 2002 to 2006; P3: 2007 to 2011.

Considering the level of analysis, results revealed a between strategy and innovation levels. Almost 52% of the articles surveyed concern TRM from the perspective of innovation and NPD (LA2), which encompasses various aspects of innovation including technology, management, Research and Development (R&D) and New Product Development (NPD). The remaining 48% focus on strategy and business (LA1) levels.

Evidences show that the majority of the studies applied qualitative approaches as research methods, supporting the notion that issues relating to TRM are still being explored and consolidated. Therefore, most of the papers that were analyzed presented specific applications that were summarized in the form of case studies. There is little evidence in the literature about quantitative research that combines concepts relating to TRM that are examined in different studies and establishes benchmarks that could analyze the complete application of the technique and determine sets of best practices, key characteristics of business practitioners and the main benefits and difficulties that resulted from the application of this approach.

An impact index showing the most-cited articles was developed. The article impact index (A_{IF}) was calculated on the basis of the number of times the article was cited (A_{TC}) and the journal impact factor, which was obtained from the Journal Citation Report (JCR_{IF}). The article impact index was calculated according to Eq. (1).

$$A_{IF} = A_{TC} * (JCR_{IF} + 1) \tag{1}$$

Table 4 presents the list of 12 papers with more than twenty citations and the calculation of the impact index of each paper. It is important to observe that considering the article impact index can change the position of one paper in the ranking of citations. An example is the paper by Groenveld [58]. If the JCR journal impact factor of the paper were not considered, that paper would be second in the ranking of citations. When the JCR journal impact factor is considered, however, its ranking changes to fifth.

Fig. 3 presents graphically the evolving trends of these citations over time. Considering the 1431 citations that were found for the 79 papers, 639 of the citations were related to the 12 most-cited articles. One noteworthy observation is that there was no significant concentration of papers from the same authors.

Table 2
Number of publications per journal and per year. Note: Journals are listed in descending order of publications relating to roadmapping.

Journal	Year														
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Total
Technological Forecasting and Social Change					1			8	1			1	6	4	1	22
Research-Technology Management	1						5	5			3	2	1	1		18
International Journal of Technology Management								1					2			3
R & D Management								1				2				3
Technovation										1	1				1	3
DYNA														2		2
IEEE Transactions on Engineering Management					1			1								2
Journal of Cleaner Production									1	1						2
Journal of Engineering and Technology Management															2	2
Journal of Systems Science and Systems Engineering											1		1			2
BT Technology Journal									1							1
Canadian Journal of Civil Engineering													1			1
Energy Policy										1						1
Engineering Management Journal											1					1
IEEE Aerospace and Electronic Systems Magazine								1								1
IEEE Robotics & Automation Magazine									1							1
IEEE Transactions on Components and Packaging Technologies									1							1
IEEE Transactions on Medical Imaging												1				1
International Journal of Computer Integrated Manufacturing												1				1
International Journal of Service Industry Management												1				1
Journal of Lightware Technology								1								1
Journal of Neuroimagin															1	1
Journal of Product Innovation Management					1											1
Journal of Systems and Software															1	1
Proceedings of the institution of mechanical engineers part B							1									1
Production Planning & Control									1							1
Revista Ingeriana e Investigation												1				1
Systems Research na Behavioral Science										1						1
Technology Analysis & Strategic Management														1		1
Technology Management in the Age of Fundamental Change													1			1
Total	1	0	0	0	3	0	6	18	6	4	6	9	12	8	6	79

Until the end of 2003 only a few papers about roadmapping were cited. The paper that was cited first and most frequently was Groenveld [58]. Groenveld [58] analyzed roadmapping initiatives at Philips Electronics with a primary focus on the early stages of the new product development process and found that roadmapping improved the integration between the company's business strategy and technology management. Another frequently cited paper is Kostoff and Schaller [5]. The objective of that research was to identify the intrinsic characteristics of the roadmap so they could be applied more effectively. Coates et al. [65] analyzed roadmapping in the context of technological forecasting, with a focus on technical features such as the levels of technical performance of machines, processes or techniques. Kappel [7] sought answers to questions regarding the effects of roadmapping, the way the identified effects could be measured, and the possible factors that could influence the results.

After 2003, all the other papers were also cited. The study by Lee and Park [61] focused on the customization of the roadmapping process so it would be able to consider forecasting, planning and administration. The study by Petrick and Echols [51] presented roadmapping as an important tool to assist investment decisions for new product development. Albright and Kappel [71] identified the strong influence of the roadmap in the creation of a database of information relating to product characteristics and in making decisions about the technology that was to be used and the market that was to be targeted. Porter et al. [33] suggested that the roadmap is an

Table 3
Publications by period showing the level of analysis and the methodological approach.

	Period					
Level of Analysis	1997 - 2001	2002 - 2006	Tendency	2007 - 2011	Tendency	Total
LA1 - Strategy & Business Level	2	17	↗	19	↗	38
LA2 - Innovation & NPD Level	2	17	↗	22	↗	41
Total	4	34		41		79
Method						
CR1: Literature review	2	8	↗	6	↘	16
CR2: Simulation or theoretical modeling	0	0		2	↗	2
ER1: Survey	0	3	↗	4	↗	7
ER2: Case study	2	23	↗	28	↗	53
ER3: Action research	0	0	-	1	↗	1
Total	4	34		41		79

important tool to analyze the future of technologies because it can be used to construct technological paths. Kostoff et al. [75] compared the advantages and disadvantages of applying the roadmapping approach for the generation of disruptive technologies that could potentially result in the creation of cheaper and better products and services. Walsh [79] focused on the industrial use of the roadmap as applied to planning for disruptive technology. McDowall and Eames [38] analyzed the literature relating to hydrogen and found that the roadmap can address the uncertainty associated with a long-term planning horizon more effectively than other approaches. The study by Phaal et al. [29] evaluated the roadmap as a tool that can be used to integrate the development of technologies with a company's business planning and to identify the presence of threats and opportunities.

4. Discussion

4.1. Bibliometric analysis

In addition to evaluating the impact of papers, bibliometric analysis can be used to map the relationships among elements addressed in these papers. The first network examined in this study was the keyword network (see Fig. 4). The ties show the keywords that have been mentioned together in the sample, and the strength of the ties corresponds to the intensity of such relationship. The main connections revealed by using this analysis are the ones between roadmapping and innovation, between innovation and science, between innovation and disruptive technology, and between business and future. Further support for these relationships was obtained from the semantic analysis. For this network, the filter that was used was set at a minimum of four citations for each keyword.

The article-to-references network (see Fig. 5) shows a list of most cited articles in the initial sample together with a list of the most frequently cited references, while the co-citation network (see Fig. 6) shows the degree of similarity between references, identifying the works that jointly cite the same texts, which may help clarify the intellectual structure of an area and map the way these groups of researchers relate to one another as well as their thematic affinities. These networks illustrate the importance of a paper in relation to the specific subject it examined. Following the criterion for the development of the networks, works that were cited within a range of 1% to 10% of the sample have been included, as suggested in the Sitkis user's [24]. The minimum number of citations that was set for inclusion in these networks was six for both articles and references.

An examination of the results shows that only six of the eighteen references were not included in the initial sample of 79 articles. Those six are: Barker and Smith [72], a study that analyzed the way BP used a roadmap to develop a strategy for research and development relating to the most important issues facing the company; Bray and Garcia [73], a study that found that the process of technology roadmapping is particularly critical when the decisions relating to investments in technology are complex but do not involve an analysis of the relationship between technology options and the goals of the organizations; Galvin [74], a study that obtained some evidence of the importance of using roadmaps in industry; Phaal et al. [77], a study that discusses the implementation of roadmapping by applying the T-Plan approach; Phaal et al. [78], a study that attributed the existence of many types of roadmaps to the lack of clear standards for the construction of roadmaps; and Willyard and McCless [3], a study that shows that roadmapping promotes the use of structured tools in planning and in the management of technology. By examining Fig. 7, it is possible to see the importance of the work led by Phaal et al. [77], Phaal et al. [78] and Phaal et al. [29] in contributing to the

Table 4
List of papers with more than twenty citations.

Article	Journal	Citations	Citations %	JCR	A_{IF}
Kostoff and Schaller [5]	IEEE Transactions on Engineering Management	116	18	1344	271,904
Groenveld [58]	Research-Technology Management	86	13	0754	150,844
Phaal et al. [29]	Technological Forecasting and Social Change	79	12	2034	239,686
Kappel [7]	Journal of Product Innovation Management	65	10	2079	200,135
McDowall and Eames [38]	Energy Policy	59	9	2629	214,111
Walsh [79]	Technological Forecasting and Social Change	47	7	2034	142,598
Kostoff et al. [76]	Technological Forecasting and Social Change	42	7	2034	127,428
Porter et al. [33]	Technological Forecasting and Social Change	39	6	2034	118,326
Albright and Kappel [71]	Research-Technology Management	32	5	0754	56,128
Coates et al. [65]	Technological Forecasting and Social Change	29	5	2034	87,986
Petrick and Echols [51]	Technological Forecasting and Social Change	25	4	2034	75,85
Lee and Park [61]	Technological Forecasting and Social Change	20	3	2034	60,68

Note: Papers in descending order of citations.

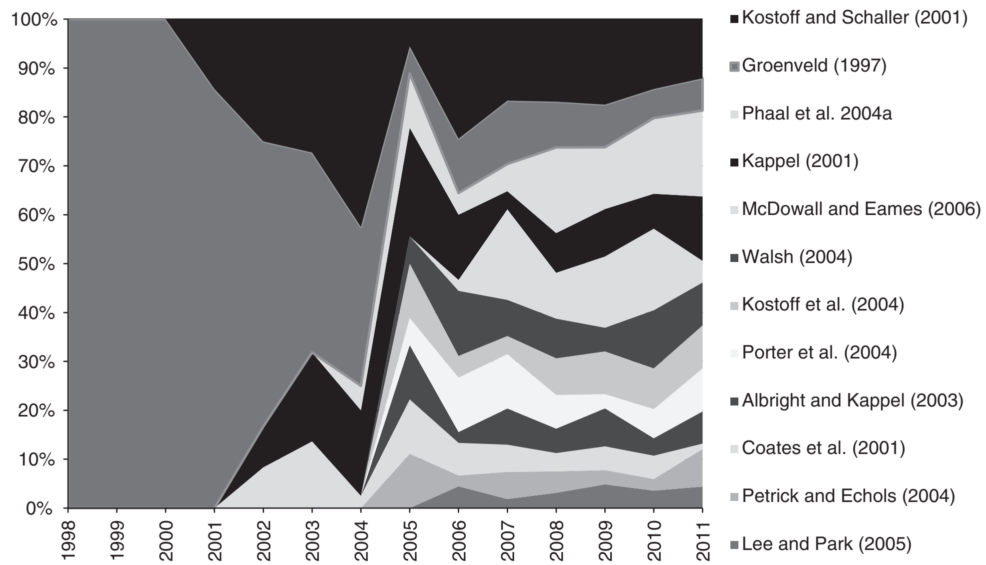

Fig. 3. Evolving trends of citations of the twelve most-cited papers.

formation of a theoretical foundation for issues relating to TRM.

After analyzing the co-citation network, the cross-citation network was developed (see Fig. 7). It displays the relationships among the articles included in the original sample so it will be possible to identify thematic clusters.

In order to better understand the patterns of relations which are found between actors and their roles, there are several indicators in bibliometrics. The centrality considers all paths in the network, and the weight of the connection between actors, and shows the most direct connections from one actor to the others in the network. This analysis can show some networks archetypes such as the stars (in our case studies with higher indegree, which means it has various cited references), spanner (in our case studies with higher outdegree, which means it has various cited references). The betweenness attempts to understand which actor sits between others in the network, showing the intermediary position of the actor, which can bridge roles in the network and in our case make the liaison between research groups.

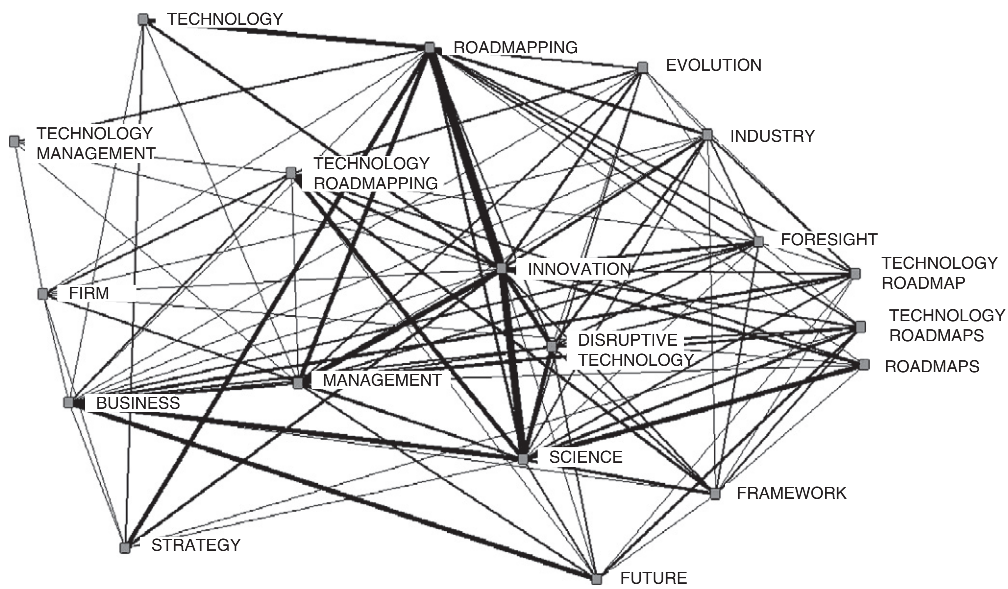

Fig. 4. Keyword network. Note: This network was created with Ucinet software using the data that was imported by using Sitkis software. The strength of ties corresponds to the relationship intensities.

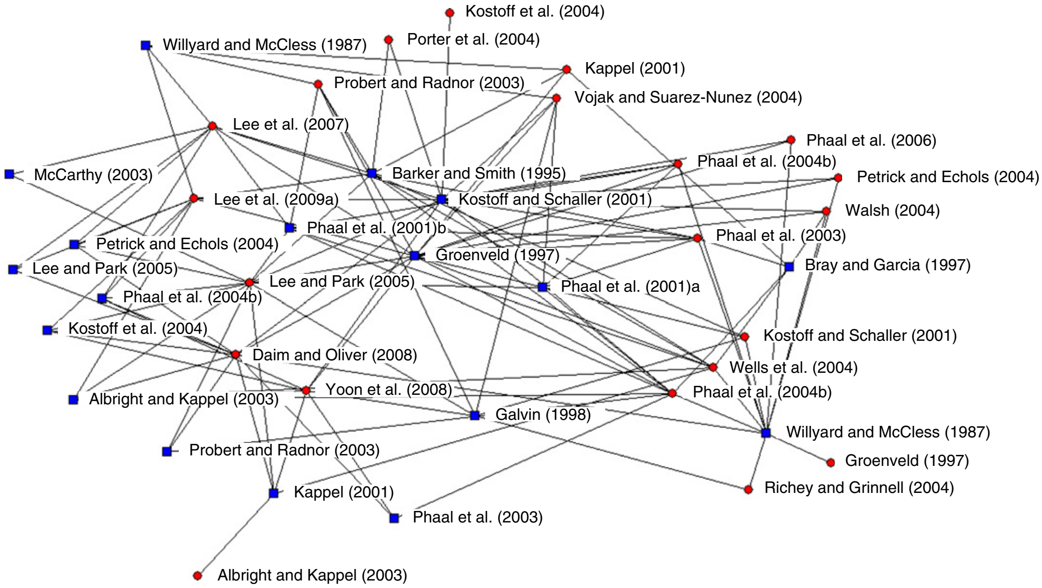

Fig. 5. Article-to-reference network. Note: This network was created with Ucinet software using the data that was imported by using Sitkis software. The red circles represent the articles and the blue scares represent the references.

This analysis required the calculation of the degrees of centrality and betweenness, which was performed using the Ucinet software (see Table 5). Degree of centrality is the adjacent relationship of an actor, in this case a study, which can be subdivided into the degree of entrance (quantity of connections that one actor receives from other actors) and the degree of exit (quantity of connections that an actor establishes with others). Degree of betweenness is the possibility that an actor has to mediate the communication between pairs of actors (studies in this case), who do not directly interact.

It is evident that the article by Gerdsri et al. [75] is a spanner because it has a relatively large number of outbound connections and it also cites several other studies in the sample. The pioneering work of Groenvelt (1997) stands out as a star because it has the highest number of inbound connections. The study by Wells et al. [2] is characterized by the highest betweenness degree.

4.2. Content analysis

The roadmapping approach is considered flexible and capable of incorporating the use of other tools to complement and enhance its initiatives to eliminate knowledge gaps and improve the results and the quality of decisions made by the managers of organizations. However, considering the

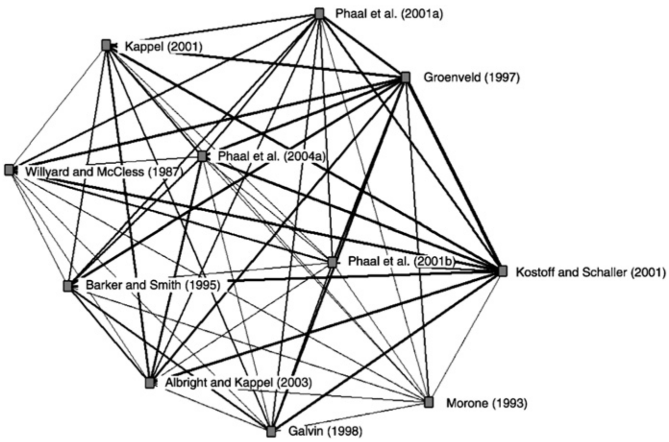

Fig. 6. Co-citation network. Note: This network was created with Ucinet software using the data that was imported by using Sitkis software.

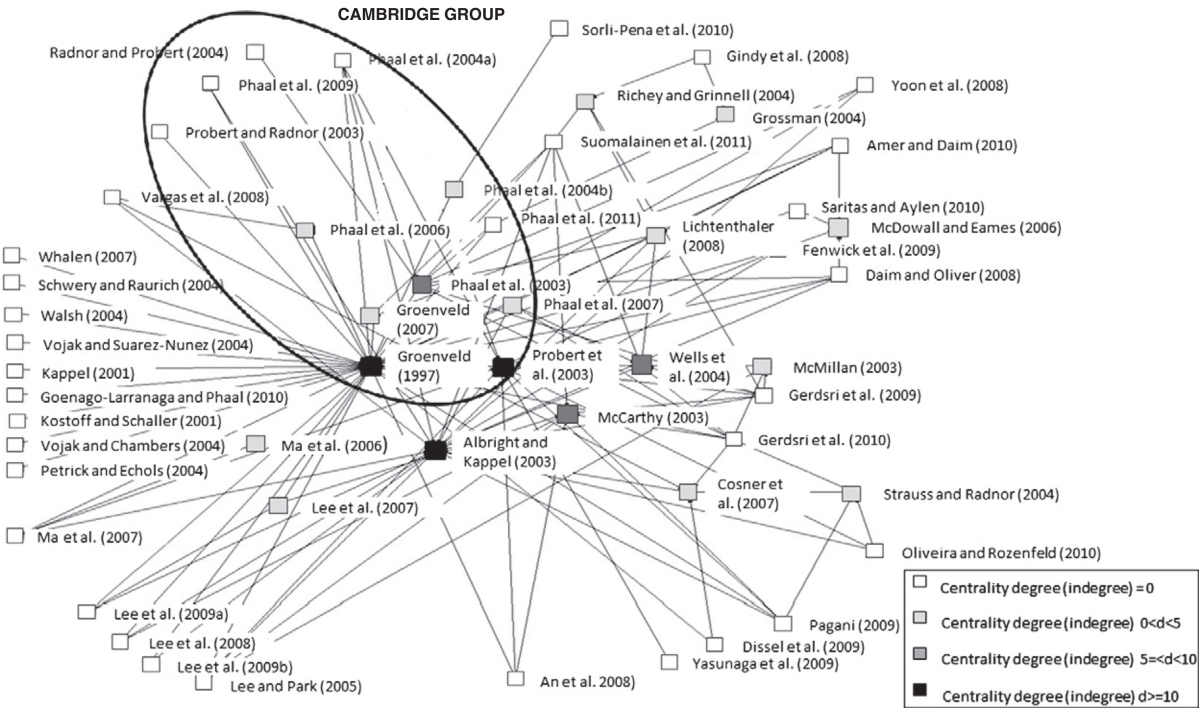

Fig. 7. Cross-citation network. Note: This network was created with Ucinet software using the data that was imported by using Sitkis software.

papers identified for this study, only ten address organizations that effectively used hybrid procedures that combined TRM with some other management technique (see Table 6).

With respect to the scope of application of the TRM, it was found that most of the studies focused on situations where TRM was used to addresses the company/product/project

Table 5
Indices of centrality and betweenness.

Article	Centrality		Betweenness	Article	Centrality		Betweenness
	Outdegree	Indegree			Outdegree	Indegree	
Gerdsri et al. [75]	8.000	0.000	0.000	Vojak and Chambers [103]	2.000	0.000	0.000
Gerdsri et al. [47]	7.000	0.000	0.000	Vojak and Suarez-Nunez [104]	2.000	0.000	0.000
Suomalainen et al. [34]	6.000	0.000	0.000	Goenago-Larranaga and Phaal [86]	1.000	0.000	0.000
Daim and Oliver [43]	5.000	0.000	0.000	Kappel [7]	1.000	0.000	0.000
Lee and Park [61]	5.000	0.000	0.000	Kostoff and Schaller [5]	1.000	0.000	0.000
Lichtenthaler [44]	5.000	1.000	4.000	Petrick and Echols [51]	1.000	0.000	0.000
Pagani [32]	5.000	0.000	0.000	Phaal et al. [95]	1.000	9.000	1.833
Amer and Daim [27]	4.000	0.000	0.000	Phaal et al. [67]	1.000	1.000	0.000
Fenwick et al. [56]	4.000	0.000	0.000	Phaal et al. [68]	1.000	1.000	1.000
Ma et al. [93]	4.000	0.000	0.000	Probert and Radnor [97]	1.000	11.000	2.333
Phaal et al. [29]	4.000	0.000	0.000	Probert et al. [1]	1.000	0.000	0.000
An et al. [40]	3.000	0.000	0.000	Radnor and Probert [98]	1.000	0.000	0.000
Lee et al. [42]	3.000	0.000	0.000	Schwery and Raurich [80]	1.000	0.000	0.000
Lee et al. [50]	3.000	0.000	0.000	Sorli-Pena et al. [100]	1.000	0.000	0.000
Oliveira and Rozenfeld [28]	3.000	0.000	0.000	Walsh [79]	1.000	0.000	0.000
Phaal et al. [30]	3.000	2.000	2.333	Whalen [64]	1.000	0.000	0.000
Phaal et al. [96]	3.000	0.000	0.000	Yasunaga et al. [37]	1.000	0.000	0.000
Vargas et al. [102]	3.000	0.000	0.000	Albright and Kappel [71]	0.000	19.000	0.000
Wells et al. [2]	3.000	5.000	5.167	Groenveld [58]	0.000	35.000	0.000
Yoon et al. [60]	3.000	0.000	0.000	Groenveld [87]	0.000	2.000	0.000
Cosner et al. [66]	2.000	3.000	3.333	Grossman [6]	0.000	2.000	0.000
Dissel et al. [52]	2.000	0.000	0.000	Ma et al. [49]	0.000	1.000	0.000
Gindy et al. [59]	2.000	0.000	0.000	McCarthy [53]	0.000	8.000	0.000
Lee et al. [90]	2.000	1.000	1.000	McDowall and Eames [39]	0.000	4.000	0.000
Lee et al. [91]	2.000	0.000	0.000	McMillan [94]	0.000	4.000	0.000
Phaal et al. [4]	2.000	0.000	0.000	Richey and Grinnell [31]	0.000	4.000	0.000
Saritas and Aylen [99]	2.000	0.000	0.000	Strauss and Radnor [69]	0.000	4.000	0.000

Note. Articles are listed in decreasing order of out-degree centrality.

[2,27–31] and industry/sector [27–29,32–35]. Possible areas of application on a smaller scale include national level TRM [27,36,37] or areas of science/technology [38,39].

The sectors that were considered most frequently in the studies were mobile communications [31,32,40–42], automotive and energy [6,27,35,38,39,43], chemical products [29,44], software, nanotechnology, mining, police, construction, medicine, academic services, hydrogen, and telecommunications [2,28,34,38,45–50].

The type of innovation that was addressed through TRM procedures was not evident from the text of most of the papers that were examined in this study. Only five papers mentioned the specific type of innovation that was involved. The research by Schwery and Raurich [80] dealt with discontinuous innovation; the research by Amaral and Caetano (2011) and by Lichtenthaler [44] dealt with open innovation; the research by McDowall and Eames [38] dealt with innovations relating to technology-push; and the research by Rozenfeld and Oliveira (2010) addressed innovations relating to market pull.

The size of the company was also not explicitly stated in most of the papers. Some of the papers related to SME companies [1,28], large companies [31,51], academia [49] and government [37,43]. Another issue addressed in the content analysis was the main advantages and limitations of using TRM. Table 7 shows the main advantages and limitations that were identified.

In particular, it shows that the main benefit includes improving the alignment between technology planning and business drivers [27,43,45,50,52,53].

The primary purpose of the qualitative approach that was used in most of the papers that were examined in this study was to explain why the analysis of technologies usually requires a long-term perspective that corresponds to the time that is necessary for a new technology to be effectively incorporated into an organization's products and services and to bring an acceptable return on the resources invested by the organization. On the other hand, the market analysis used by organizations is usually medium-term, reflecting the time period in which a person can identify the main opportunities and threats and can then develop plans of action. Therefore, the alignment of these two perspectives generates relevant knowledge for the participants, who can clearly understand the impact of market opportunities for the management of the key technologies. Specifically, the papers examined in this study show how this alignment is reflected in the organization. A second important benefit of TRM that was identified in the papers is its flexibility and its ability to provide relevant results in the context of the diverse organizations that were surveyed [46,54]. This flexibility also relates to the main disadvantages that were mentioned previously because there are no clearly established procedures for the approach. Attempts to implement the TRM approach may not be applicable to a specific organization and can lead to poor results [50,55,56].

The phases of the roadmapping process were also analyzed. Some authors specify two or three steps, while other authors provide a more detailed explanation of the process, as shown in Table 8.

It is evident that despite the differences in the specific activities associated with the TRM initiatives described in different papers, there is a consensus about the three main phases that must be considered: preparation (when decisions are made); implementation (when initiatives are executed) and finalization, when the results of the process are consolidated and disseminated and major decisions are made about the continuation of the process.

Finally, the conditions that must be satisfied for the roadmapping process to achieve good results were analyzed (see Table 9). Some of the conditions are rather general and are frequently mentioned in relation to various management techniques, but others relate to the very specific criteria for the roadmap approach.

Table 6
Tools used by the authors.

Tools	Referency
Strategy analysis; SWOT	Pagani [32]; Fenwick et al. [56]
Analytic hierarchy process	Fenwick et al. [56]
Competitive features matrix	Fenwick et al. [56]
Delphi; PEST	Fenwick et al. [36]; Saritas and Oner [56]
Eco-design	McDowall and Eames [38]
Five forces analysis	Fenwick et al. [32]; Pagani [56]
Integrated management model	Saritas and Oner [36]
Morphological matrix	Yoon et al. [60]
Perceptual map rank valuation	Fenwick et al. [56]
Portfolio management	Oliveira and Rozenfeld [28]; Phaal et al. [68]
QFD	An et al. [40]; Lee et al. [91]
Scenarios	McDowall and Eames [32]; Pagani [38]
Technology development envelope	Fenwick et al. [56]
Technology management tools	Phaal et al. [1]; Probert et al. [68]
Value proposition	Fenwick et al. [56]

4.3. Semantic analysis

A list of the definitions that were used in the semantic sample space analyzed in this study is included in Appendix II. The definitions were first analyzed and grouped into three categories, namely "roadmap", "roadmapping" and "technology roadmapping". In the first group dynamic conducted, which lasted for almost three hours, the researchers found that almost all the definitions of "roadmapping" and "technology roadmapping" were related to the roadmapping process but that the definitions of "roadmap" were related to the outcome of the process, namely to the map that was developed.

Based on this finding, most of the definitions of "roadmapping" and "technology roadmapping" were analyzed jointly as one category. Only two of the definitions of "roadmapping" were not analyzed in this category because they were more aligned with the definitions of "roadmap" [7,57].

In the "roadmapping + technology roadmapping" category, two definitions focus explicitly on processes [2,58]. Six studies explored the link between the TRM and strategy [27,47,57–60]. Other interesting issues that were explored in the semantic sample space were the planning horizon [5,41,43,46,55], communication [2,7,35,40,60] and flexibility [27,61].

For these two categories of definitions (i.e., "roadmapping + technology roadmapping" and "roadmap") semantic analyses were conducted based on the frequency of occurrence for

Table 7
Limitations and advantages of the roadmap.

	Abe et al. (2009)	Amadi et al. (2011)	Amer and Daim (2010)	Daim and Oliver (2008)	Dissel et al. (2009)	Elliott (2005)	Fenwick et al. (2009)	Galvin (2004)	Groenveld (1997)	Grossman (2004)	Kostoff et al. (2004)	Lee and Park (2005)	Lee et al (2009a)	McCarthy (2003)	McMillan (2003)	Probert and Radnor (2003)	Saritas and Aylen (2010)	Talonen and Hakkarainen (2008)	Wall et al. (2005)	Total
LIMITATIONS																				
Are normative, more than exploratory																	x			1
Difficult to disseminate																	x			1
Difficult to evaluate business value	x																			1
Difficult to express a business attractiveness of R&D outputs	x																			1
Difficult to express a business system or operation model	x																			1
Difficult to customizing												x								1
Encourages linear and isolated thinking																	x			1
Provides little guidelines													x							1
Lacks focus and clear boundaries							x													1
Lacks reliability and objectivity													x							1
ADVANTAGES																				
Aligns technology with overall business objectives		x	x	x	x								x	x						6
Can be utilized as a strategic planning tool	x																			1
Can help develop consensus among decision makers											x									1
Combines internal development needs with a market-place view																x				1
Connects the future with the present																	x			1
Enables assessment of emerging technologies from the learning obtained														x						1
Establishes of a shared product-technology strategy									x											1
Focuses on discussion around specific steps of the process														x						1
Focuses on longer-term planning				x																1
Focuses on planning with priority setting				x																1
Improves the communication and ownership of plans				x																1
Improves the time-to-market and time-to-money									x											1
Improves the dialogue between projects and vehicle programs										x										1
It is flexible						x									x					2
It is scalable															x					1
Links the business drivers and the market trends			x							x										2
Provides a landscaped	x																			1
Provides a means for the development of advanced technologies		x																		1
Provides a mechanism to help experts forecast science and technology											x									1
Provides a simple method to solution complicated issues														x						1
Provides a visual map																		x		1
Provides an direction																			x	1
Provides an extended look at the future								x												1
Provides high information content in one single figure																	x			1
Provides information to help make better science and technology investments											x									1
Stimulates the learning and communications									x											1
Total																				43

the relationships between verbs, adjectives and nouns (see Table 10). In addition, three types of graphs were plotted: star, actor, and area (see Figs. 8, 9 and 10).

In a second session conducted by the researchers, panels showing an affinity diagram of the definitions were available and the semantic graphs were generated using the Tropes software (which was also available for online access) for the category "roadmapping + technology roadmapping". After considering the content and semantic analysis, two definitions of TRM were proposed. The first definition represents the synthesis of the semantic sample space surveyed, using descriptive statistics of verbs, adjectives and nouns and their relationships. The second definition was the one proposed by the research group on the basis of the group members' assessment of the most important factors that should be taken into account in defining TRM (such as strategic resources and competencies) even if those factors were rarely present in the definitions analyzed in this study. In a third group dynamics session, the same procedure was used in relation to the "roadmap" category to obtain a definition representing the synthesis of the semantic sample space and

Table 8
Phases of the roadmapping process.

Phases	Referency
Preliminary activity/initiation Roadmap development Follow-up-activity/integration	Amer and Daim [27]; Gerdsri et al. [47]; Saritas and Aylen [99]
Identification of the needs and drivers Identification of products or services to meet the needs and the drivers Identification of technologies to support the products or services Establishment of the linkages among the first three steps above Developing plans to acquire or develop the technologies Assign resources to accomplish the plans for acquisition and development	Daim and Oliver [43]
Initiation Select subject Assessment of technology needs Develop technology plan Implementation Follow-up activity	Lee et al. [90]
Form group Explain from knowledge coordinators Description of present situation Every member's current status and idealized design Research schedule and study schedule Implementation and control	Ma et al. [49]
Environmental scan Organizational scan Emergence roadmapping Collaborative research strategy framework	Phaal et al. [96]
Specify underlying assumptions Assess drivers of change in the environment Assess strategic implications of the above Define initial issues for composite approach Develop scenarios Create barebones roadmaps for each scenario Define checkpoints Consider significant variations in tasks, decisions and resource Identify corporate drivers Define the "window" in which one can transition to a strategy fitting the emerging scenario Specify potential "flex" points Translate the tasks, decision points, checkpoints, indicators, and external developments Flesh out the roadmap Continually refine scenarios Regularly re-evaluate scenarios	Strauss and Radnor [69]

also the group's proposal for a definition of "roadmap". The definitions are presented in Table 11.

It is important to note that the definitions that are presented above all relate to the TRM processes that occur in the context of a single company and not to the TRM process that apply to nations or industrial sectors. Another factor that should be incorporated into both of the definitions in future research relates to the knowledge management processes that support TRM and the roadmap. The TRM process and its synthesis both involve the mechanisms explained by knowledge theory relating to the interaction between tacit and explicit knowledge and to various modes of knowledge conversion, such as socialization, externalization, combination and internalization [62,63].

Table 9
Conditions necessary for high quality.

Conditions necessary for high quality	Referency
Include the right people There must be commitment from the client The technology roadmap conclusions must be implemented There should be a dissemination plan to capitalize and ensure increased participation There should paint a realistic picture of the nontechnical barriers There should provide broad recognition of competing technologies	Elliott [49]
Senior management commitment Role of roadmap manager Competence of roadmap participants Stakeholder-driven Normalization and standardization Roadmap criteria Reliability Relevance to future actions Cost Global data awareness	Kostoff et al. [76]
Integrate TRM with existing management tools Finding ways to increase the efficiency and effectiveness of the roadmapping process	Lee et al. [90]
Business unit (who is/are the customers?) Engineering discipline (material science, power, etc.) Market requirements (geography, industry and application) Core competencies Technology timing	McMillan [94]
Participation of administrative authorities and coordinators Customized solutions Internet-based groupware Graphical presentation tools Simulations Critical debate Brainstorming Idealized design	Yamashita et al. [105]

5. Conclusions

Studies (i.e., articles and the reference citations) were systematically analyzed using a hybrid approach that combined several literature review methodologies (including bibliometric techniques, social network analysis, content analysis and semantics analysis) to identify trends and gaps in the literature relating to TRM.

Several authors have claimed that the roadmapping approach is very popular and widespread [1,5,64], but there was little or no evidence from localized surveys of management practices that could support these assertions. The absence of such evidence highlights a gap in the literature and suggests a need for new research initiatives to fill it.

Table 10
Tropes statistics report.

	TRM + roadmapping		Roadmap	
	Word	Frequency	Word	Frequency
Reference fields 1 (Main themes ranked by frequency*)	Technology (technique, technology)	22	Technology (technique(s), technology(ies))	8
	Business (business, market, investiment, firm, enterprise)	12	Device (tool)	5
	Goods (product)	5	Location (field, area)	3
	Device (tool)	4	Way (paths, routes)	3
	Time (time, future)	4	Goods (product)	3
	Social_group (managers, leads)	3		
	Communication (communication, information)	3		
	Organization	3		
Relations (Tightly connected*)	Technology roadmapping > technology	5	Roadmap > tool	5
	Technology > merchandise	4		
	Technology > technology roadmapping	4		
	Technology > strategy	4		
	Tool > technology	4		
	Technology roadmapping > technique	4		
	Technology roadmapping > management	3		
	Technology roadmapping > tool	3		
	Business > technology roadmapping	3		
	Technology roadmapping > similarity	3		
	Technology > time	3		

* At least three times.

In regard to methodological approaches that were presented by the papers identified in this study, the most common approach was exploratory qualitative research based on case studies. Although most of the papers described cases where roadmapping initiatives had been successfully implemented, the papers had several methodological weakness, and they were unable to provide strong evidence regarding the relationship between the application of TRM and positive innovation performance outcomes (such as increased number of patents, a reduction of the time required for the product development cycle, and increased sales from new products) or general organization performance (such as market share). Some studies reinforce this conclusion [107,108]. Cooper and Edgett [103], for instance, previously suggested the important correlation between strategic roadmap and business performance, related to new products and technology development initiatives [108]. Vatananan and Gerdsri [107] also corroborate the lack of evaluation of the effectiveness of TRM outputs and outcomes, and suggest that future researches develop evaluation procedures and measures [107].

In general, most of the existing studies described the benefits of TRM primarily on the basis of the perceptions of the stakeholders who were involved. Researchers were unable to identify any studies that measured the benefits of TRM

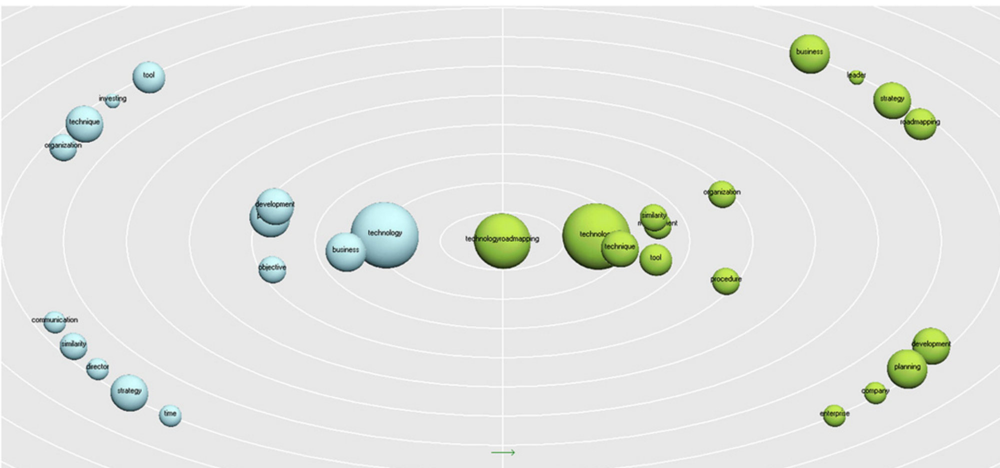

Fig. 8. Example of an area graph for the definitions of TRM and roadmapping. Note: The surface of the sphere is proportional to the number of words contained in the sphere. The distance between the central class and the others is proportional to the number of relations connecting them.

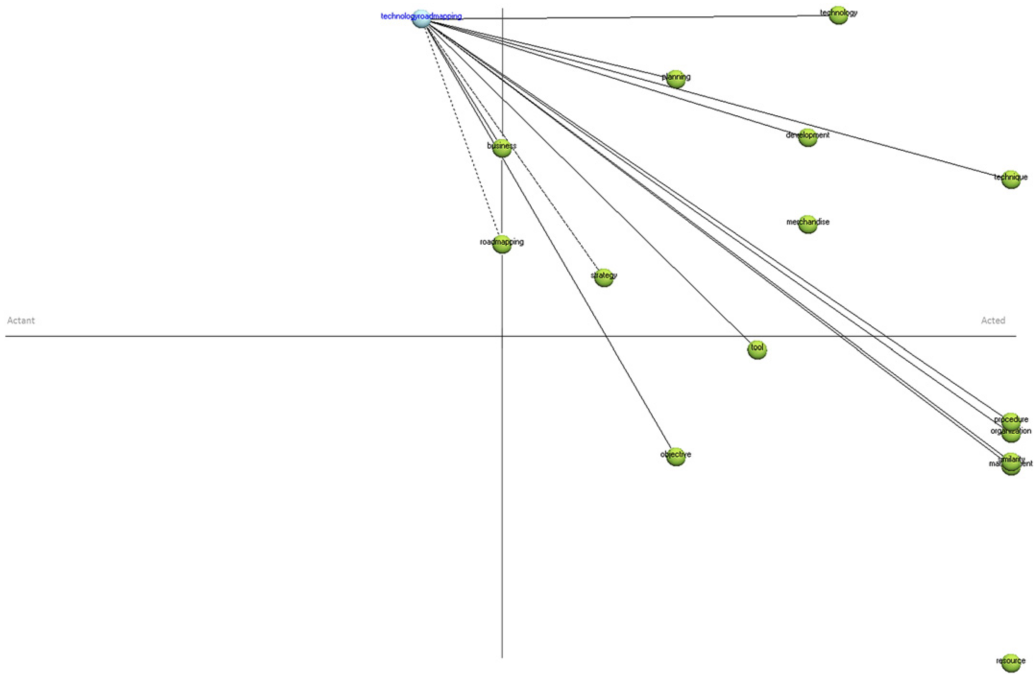

Fig. 9. Example of an actor's graph linked to the definitions of TRM and roadmapping. Note: The X axis (horizontal) shows the actant/acted ratio (from left to right). The Y axis (vertical) shows the concentration of relationships for each reference displayed (strong at the top of the graph, weak at the bottom). The lines show the relationships between the reference and the others.

quantitatively, or that provided empirical support for the hypothesis that TRM has a significant positive impact on innovation or organizational performance.

This should, therefore, be part of a future research agenda.

Although some of the papers surveyed in this study did contain a literature review [4,5,27,38,39,51,53,54,61–70], but few of them applied a systematic literature review methodology. Instead, what they presented consists primarily of a compilation of the tools, scope, practices and stages of the TRM process. Two articles have been identified by applying bibliometrics [107,109]. Vatananan and Gerdsri [107] provide a general review of TRM publications, in order to discuss important issues such as example objectives, functions, architecture, implementation, tools, challenges, gaps and research opportunities [107]. Gerdsri et al. [109] conducted a similar research, where the evolution of the TRM field was mapped through bibliometric analysis, based on papers published in journals and conferences (ISI Web of Science and IEEE Explore) [109]. Thus, this paper has been able to update those previous studies and go further into merging different methodological approaches for systematic literature review (bibliometrics, semantics and content analysis) by analyzing in depth the surveyed studies so as to the trends and gaps in the literature.

There is a strong interest among academics and practitioners in identifying the critical success factors (CSFs) for the application of TRM. As shown in the content analysis results in this paper (see Table 9), some authors have listed the CSFs for the implementation of TRM, but there are no studies that have demonstrated the magnitude or the statistical significance of these factors. It is, therefore, not possible to establish robust benchmarks relating to the incorporation of these CSFs. Moreover, there is a lack of empirical evidence about the way other factors such as industrial sector, firm size, or other important moderator variables might moderate the

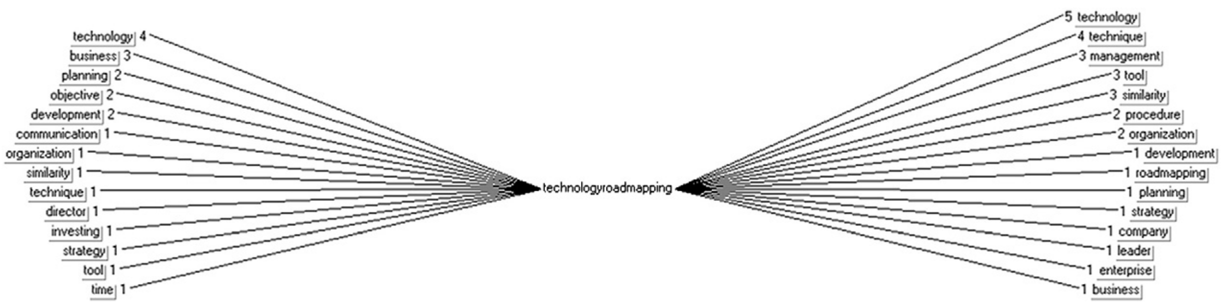

Fig. 10. Example of stars graph linked to the definitions of TRM and roadmapping. Note: References to the left of the central reference are the predecessors of the central reference and the references to the right are its successors.

Table 11
Definitions of technology roadmapping (TRM) and roadmap.

Phases	Referency
Preliminary activity/initiation	Amer and Daim [27];
Roadmap development	Gerdsri et al. [47];
Follow-up-activity/integration	Saritas and Aylen [99]
Identification of the needs and drivers	Daim and Oliver [43]
Identification of products or services to meet the needs and the drivers	
Identification of technologies to support the products or services	
Establishment of the linkages among the first three steps above	
Developing a plan to acquire or develop the technologies	
Assign resources to accomplish the plans for acquisition and development	
Initiation	Lee et al. [90]
Select subject	
Assessment of technology needs	
Develop technology plan	
Implementation	
Follow-up activity	
Form group	Ma et al. [49]
Explain from knowledge coordinators	
Description of present situation	
Every member's current status and idealized design	
Research schedule and study schedule	
Implementation and control	
Define strategic framework, vision, scenario	Dissel et al. [52]
Map technology development and investment milestones	
Define value streams.	
Map market and business trends and drivers.	
Map barriers and enablers.	
Review project plan and VRM.	
Present visualization.	
Maintain VRM as a process	
Planning	Phaal et al. [30]
Strategic landscape	
Identify innovation opportunities	
Explore priority opportunities	
Way forward	
Review	Probert et al. [1]
Setting up the process	
Market workshop	
Product workshop	
Technology workshop	
Roadmapping workshop	
Following on from the process	
Specify underlying assumptions	Strauss and Radnor [69]
Assess drivers of change in the environment	
Assess strategic implications of the above	
Define initial issues for composite approach	
Develop scenarios	
Create barebones roadmaps for each scenario	
Define checkpoints	
Consider significant variations in tasks, decisions and resource	
Identify corporate drivers	
Define the “window” in which one can transition to a strategy fitting the emerging scenario	
Specify potential “flex” points	
Translate the tasks, decision points, checkpoints, indicators, and external developments	
Flesh out the roadmap	
Continually refine scenarios	
Regularly re-evaluate scenarios	

effects of the CSFs. These issues should provide a direction for future research.

Issues regarding the interface between roadmapping and other initiatives that are vital to innovation and corporate strategy, including strategic resources and competences, knowledge management, organizational communications and the management of stakeholder relations are also poorly addressed in the literature that was surveyed. For instance, the link between TRM and strategic alignment could be explored [110]. The application of the TRM could lead to expanded opportunities to address all these related issues in an integrated way. This possibility could be thoroughly investigated in future research.

Another future research perspective involves the possible application of roadmapping approaches to issues of sustainability. One paper by Donnelly et al. [41] presented a link to a proposal for an eco-roadmap. Because many industries (including the automotive industry) have carbon reduction targets that can only be achieved by addressing the relevant technological issues, the application of TRM to sustainability initiatives is a theme that calls out for further analysis.

This study has limitations resulting from methodological choices that were made. The first relates to a decision to rely on ISI Web of Science for the generation of the initial sample. ISI Web of Science is an important database where all the journals are indexed, and it facilitates the use of JCR for the calculation of the journal impact factor. It was reasonable to assume that this database would be able to capture the main contributions that had been published on TRM. On the other hand, ISI Web of Science has a limited number of titles so it is possible that some relevant papers may not have been included in the sample. Another limitation of the study is the bias that could have resulted from the bibliometric analysis and co-citation because these methodologies focus on the works that have been cited most often on the assumption that they are the ones that had the greatest impact on an area of knowledge. In practice, the most-cited papers and references tend to be the ones that are the oldest, so this tendency generates a temporal bias. These limitations were partially mitigated, however, by our use of content analysis, the snowball method and semantics techniques that offer a more analytical and qualitative approach.

Finally, this paper concludes by highlighting directions for future research on TRM. The literature in this area could be enhanced by future research in the following areas: the development of quantitative research in this field; quantitative measurement of the impact of TRM on organization outcomes; the establishment of benchmarks for critical success factors; and an explicit alignment of TMR with other initiatives to promote innovation and strategy such as analysis of strategic competencies, knowledge management and sustainability drivers.

Acknowledgments

The authors wish to express their gratitude towards the referees who have contributed substantially to the improvement of this article. We thank CAPES and CNPq for supporting this research project.

Appendix I. Tabulation of the 79 articles — Journal, level and method

Article	Journal	Level	Method
Abe et al. [55]	Technological Forecasting and Social Change	LA2	ER2
Albright and Kappel [71]	Research-Technology Management	LA1	ER2
Amadi et al. [45]	Journal of Engineering and Technology Management	LA2	ER2
Amer and Daim [27]	Technological Forecasting and Social Change	LA3	CR1
Caetano and Amaral [81]	Technovation	LA2	ER3
Christensen [82]	IEEE Robotics & Automation Magazine	LA1	ER2
Coates et al. [65]	Technological Forecasting and Social Change	LA2	CR1
Cosner et al. [66]	Research-Technology Management	LA1	CR1
Daim and Oliver [43]	Technological Forecasting and Social Change	LA2	ER2
Dissel et al. [52]	Research-Technology Management	LA2	ER2
Donnelly et al. [41]	Journal of Cleaner Production	LA1	ER2
Elliott [46]	BT Technology Journal	LA1	ER2
Fenwick et al. [56]	Technological Forecasting and Social Change	LA1	ER2
Foden and Berends [83]	Research-Technology Management	LA1	ER2
Froese [57]	Canadian Journal of Civil Engineering	LA2	ER1
Galvin [84]	Technological Forecasting and Social Change	LA1	ER1
Gerdsri et al. [47]	Technological Forecasting and Social Change	LA1	ER2
Gerdsri et al. [75]	Technology Analysis & Strategic Management	LA1	ER2
Geum et al. [85]	Journal of Engineering and Technology Management	LA1	ER2
Gindy et al. [59]	International Journal of Computer Integrated Manufacturing	LA1	ER2
Goenago-Larranaga and Phaal [86]	DYNA	LA1	ER2
Groenveld [58]	Research-Technology Management	LA1	ER2
Groenveld [87]	Research-Technology Management	LA1	ER2
Grossman [6]	Research-Technology Management	LA2	ER2
Hansis et al. [48]	IEEE Transactions on Medical Imaging	LA2	ER1
Hicks et al. [88]	IEEE Aerospace and Electronic Systems Magazine	LA1	ER2
Kappel [7]	Journal of Product Innovation Management	LA1	ER2
Korotky [89]	Journal of Lightware Technology	LA1	ER1
Kostoff and Schaller [5]	IEEE Transactions on Engineering Management	LA2	CR1
Kostoff et al. [76]	Technological Forecasting and Social Change	LA2	ER2
Lee and Park [61]	Technological Forecasting and Social Change	LA1	CR1
Lee et al. [90]	Technovation	LA1	ER2
Lee et al. [42]	R & D Management	LA2	CR2
Lee et al. [50]	Technological Forecasting and Social Change	LA1	ER1
Lee et al. [91]	International Journal of Technology Management	LA2	ER1
Levitt et al. [92]	Journal of Neuroimagin	LA2	ER2
Lichtenthaler [44]	Research-Technology Management	LA2	ER2
Ma et al. [49]	Systems Research and Behavioral Science	LA2	ER2
Ma et al. [93]	Journal of Systems Science and Systems Engineering	LA2	ER2
McCarthy [53]	Research-Technology Management	LA2	CR1
McDowall and Eames [38]	Energy Policy	LA1	CR1
McMillan [94]	Research-Technology Management	LA2	ER2
Na et al. (2008)	International Journal of Service Industry Management	LA1	ER2
Oliveira and Rozenfeld [28]	Technological Forecasting and Social Change	LA1	ER2
Pagani [32]	Technological Forecasting and Social Change	LA3	ER2
Petrick and Echols [51]	Technological Forecasting and Social Change	LA2	CR1
Phaal and Muller [54]	Technological Forecasting and Social Change	LA1	CR1
Phaal et al. [95]	Research-Technology Management	LA2	ER2
Phaal et al. [29]	Technological Forecasting and Social Change	LA3	ER2
Phaal et al. [67]	International Journal of Technology Management	LA1	CR1
Phaal et al. [68]	Technovation	LA2	CR1
Phaal et al. [30]	Engineering Management Journal	LA2	ER2
Phaal et al. [4]	International Journal of Technology Management	LA3	CR1
Phaal et al. [96]	Technological Forecasting and Social Change	LA1	ER2
Porter et al. [33]	Technological Forecasting and Social Change	LA2	ER2
Probert and Radnor [97]	Research-Technology Management	LA2	ER2
Probert et al. [1]	Proceedings of the institution of mechanical engineers part B	LA1	ER2
Radnor and Probert [98]	Research-Technology Management	LA2	ER2
Richardson et al. [39]	IEEE Transactions on Components and Packaging Technologies	LA2	CR1
Richey and Grinnell [31]	Research-Technology Management	LA2	ER2
Saritas and Aylen [99]	Technological Forecasting and Social Change	LA1	ER2
Saritas and Oner [36]	Technological Forecasting and Social Change	LA1	ER2
Schwery and Raurich [80]	R & D Management	LA2	ER2
Sorli-Pena et al. [100]	DYNA	LA2	ER2
Strauss and Radnor [69]	Research-Technology Management	LA1	CR1
Suomalainen et al. [34]	Journal of Systems and Software	LA1	ER2
Talonen and Hakkarainen [70]	Research-Technology Management	LA1	CR1
Tuominen and Ahlqvist [35]	Technological Forecasting and Social Change	LA3	ER2
Van den Bosch et al. [101]	Journal of Cleaner Production	LA1	ER2

(continued on next page)

Appendix I (*continued*)

Article	Journal	Level	Method
Vargas et al. [102]	Revista Ingeriana e Investigation	LA1	ER2
Vojak and Chambers [103]	Technological Forecasting and Social Change	LA2	ER1
Vojak and Suarez-Nunez [104]	IEEE Transactions on Engineering Management	LA2	ER2
Wall et al. [105]	Production Planning & Control	LA1	ER2
Walsh [79]	Technological Forecasting and Social Change	LA1	ER2
Wells et al. [2]	Research-Technology Management	LA1	ER2
Whalen [64]	Research-Technology Management	LA2	CR1
Yamashita et al. [106]	Journal of Systems Science and Systems Engineering	LA2	ER2
Yasunaga et al. [37]	Technological Forecasting and Social Change	LA2	ER2
Yoon et al. [60]	R & D Management	LA3	CR2

Appendix II. List of definitions by category

Reference	Definition
	Roadmapping
Froese [57]	Roadmapping is a strategic visioning exercise intended to address several questions - as implied by the analogy to literal roadmaps: where are we? Where are we going? How do we get there?
Kappel [7]	Roadmapping (the activity) can be done for different purposes, while roadmaps (the documents) can address different aspects of a planning problem.
	Roadmapping is the activity of creating and then communicating the roadmap
	Roadmapping + technology roadmapping
Abe et al. [55]	Technology-roadmapping is a new technology development plan and/or new product-development plan that take into account social trends, resource conditions, and so forth. It can easily find and eliminate various discrepancies between development schedules on a time axis
Amer and Daim [27]	Technology-roadmapping is a very flexible and powerful approach widely used in industry for strategy planning and integrating business and technology
An et al. [40]	Technology-roadmapping is a powerful technique for supporting technology management and planning, especially for exploring and communicating the dynamic linkages between technological resources, organizational objectives and the changing environment
Daim and Oliver [43]	Technology-roadmapping is a strategic and operational approach used extensively in business today to help organizations chart technology issues important to their future success
	Technology-roadmapping is a comprehensive approach for strategy planning to integrate science/technological considerations into product and business aspects as well as to provide a way to identify new opportunities in achieving a desired objective from the development of new technologies
Gerdsriet al. (2009)	Roadmapping is a strategic management tool to help organizations in effectively identifying potential products or services for the future, determining proper technology alternatives, and mapping them with resource allocation plans
Gindy et al. [59]	At the enterprise level, technology-roadmapping is primarily a management tool to improve the enterprise's strategic technology planning processes by aligning technology acquisition to company strategic objectives derived from market and business drivers
Groenveld [58]	Roadmapping is a process that contributes to the integration of business and technology and to the definition of technology strategy by displaying the interaction between products and technologies over time, taking into account both short and long term product and technologies aspects

Appendix II (*continued*)

Reference	Definition
Lee et al. [91]	Technology-roadmapping is a useful technique companies can employ to support the development of technologies and related business strategies
McMillan [94]	Technology-roadmapping is a backbone that leads to focusing attention
Phaal et al. [29]	Technology-roadmapping is a flexible technique that is widely used within industry to support strategic and long-range planning
Saritas and Aylen [99]	Roadmapping are a used future technique which helps R&D managers set priorities for research
Tuominen and Ahlqvist [35]	Roadmapping is a methodology that has been applied in several industrial organizations in order to facilitate and communicate technology strategy and planning
Wells et al. [2]	Technology-roadmapping is a process and communication tool to aid strategic decision-making
	Technology-roadmapping is an important tool for technology planning and coordination at strategic level, helping senior managers to make better technology investment decisions
Yoon et al. [60]	Technology-roadmapping is an effective technique for addressing these challenges, supporting the gathering of information, decision making and communication, in the context of strategic technology planning
	Roadmap
Caetano and Amaral [81]	Roadmap is a method that helps organizations plan their technologies by describing the path to be followed in order to integrate a given technology into products and services
Donnelly et al. [41]	Product eco-roadmap is a concise graphical tool that captures short-and-long-term environmental drivers in one document
Elliott [46]	Roadmap is a snapshot of how the future seems now and need to be kept alive by being revisited and refreshed on a regular basis
Grossman [6]	Roadmap is a framework for meaningful discussions between key stakeholders about the development schedule and funding issues
Kostoff and Schaller [5]	Roadmap is a layout of paths or routes that exists (or could exist) in some particular geographical space
	Roadmap is an 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
Lee and Park [61]	Roadmap is a powerful and inherently flexible approach in terms of architectural structure and construction process

Appendix II (*continued*)

Reference	Definition
Lee et al. [90]	Roadmap is a management tool to support strategic and long-term R&D planning Roadmap is considered to be one of the most powerful techniques used to support technology management and planning
Lee et al. [42]	Roadmap is an effective tool for connecting product and technology planning
Ma et al. [49]	Roadmap is a layout of paths or routes that exists (or could exist) in some particular geographical space
McMillan [94]	Roadmap is a company knowledge filter
Phaal et al. [4]	Roadmap is an 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
Probert and Radnor [97]	Roadmap is the view of a group of stakeholders as to how to get where they want to go to achieve their desired objective
Probert et al. [1]	Roadmap is a powerful communication tool, both within the company to demonstrate why a particular course of action is necessary, and also to the outside world
Strauss and Radnor [69]	Roadmap is a visual tool that identifies and describes specific customer requirement-driven technology clusters and specifies potential discontinuities and critical requirements related to technology decisions

References

[1] D.R. Probert, C.J.P. Farrukh, R. Phaal, Technology roadmapping—developing a practical approach for linking resources to strategic goals, Proc. Inst. Mech. Eng. B J. Eng. Manuf. 217 (9) (2003) 1183–1195.
[2] R. Wells, R. Phaal, C.J.P. Farrukh, D.R. Probert, Technology roadmapping for a service organization, Res. Technol. Manag. 47 (2) (2004) 46–51.
[3] C.M. Willyard, C.W. McCless, Motorola's technology roadmap process, Res. Manag. 30 (5) (1987) 13–19.
[4] R. Phaal, C.J.P. Farrukh, D.R. Probert, Visualising strategy: a classification of graphical roadmap forms, Int. J. Technol. Manag. 47 (4) (2009) 286–305.
[5] R.N. Kostoff, R.R. Schaller, Science and technology roadmaps, IEEE Trans. Eng. Manag. 48 (2) (2001) 132–143.
[6] D.S. Grossman, Putting technology on the road, Res. Technol. Manag. 47 (2) (2004) 41–46.
[7] T.A. Kappel, Perspectives on roadmaps: how organizations talk about the future, J. Prod. Innov. Manag. 18 (1) (2001) 39–50.
[8] J.H. Littell, J. Corcoran, V. Pillai, Systematic Reviews and Meta-Analysis, Oxford University Press, New York, 2008.
[9] V.P. Diodato, Dictionary of Bibliometrics, The Haworth Press, New York, 1994.
[10] S. Prasad, J. Tata, Publication patterns concerning the role of teams/groups in the information systems literature from 1990 to 1999, Inf. Manag. 42 (8) (2005) 1137–1148.
[11] A. Neely, The evolution of performance measurement research: developments in the last decade and a research agenda for the next, Int. J. Oper. Prod. Manag. 25 (12) (2005) 1264–1277.
[12] J.E. Hunter, F.L. Schmidt, G.B. Jackson, Meta-analyzes: Cumulating Research Findings Across Studies, Sage Publications, Beverly Hills, 1982.
[13] H.D. White, K.W. McCain, Visualizing a discipline: an author co-citation analysis of information science, 1972–1995, J. Am. Soc. Inf. Sci. 49 (4) (1998) 327–355.
[14] L. Ikpaahindi, An overview of bibliometrics — Its measurements, laws and their applications, Libri 35 (2) (1985) 163–177.
[15] A.-R. Ramos-Rodríguez, J. Ruíz-Navarro, Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal, 1980–2000, Strateg. Manag. J. 25 (10) (2004) 981–1004.
[16] J.R. Bellegarda, Exploiting latent semantic information in statistical language modeling, Proc. IEEE 88 (8) (2000) 1279–1296.
[17] T.I. Wang, K.H. Tsai, Interactive and dynamic review course composition system utilizing contextual semantic expansion and discrete particle swarm optimization, Expert Syst. Appl. 36 (6) (2009) 9663–9673.
[18] A. Fink, How to Sample in Surveys, Sage Publications, London, 1995.
[19] A. Fink, The Survey Handbook, Sage Publications, London, 1995.
[20] J.A. Carnevalli, P.A.C. Miguel, Review, analysis and classification of the literature on QFD—Types of research, difficulties and benefits, Int. J. Prod. Econ. 114 (2) (2008) 737–754.
[21] F.J.R. Cabestre, L.A.G. Martín, A.V.R. Vega, El estado actual de la investigación empírica sobre economía de la empresa: Análisis de las publicaciones españolas, in: Papeles de Economía Española, 78-79, 1999, pp. 302–317.
[22] M.J. Culnan, Mapping the intellectual structure of MIS, 1980–1985: a co-citation analysis, MIS Q. 11 (3) (1987) 341.
[23] M.J. Culnan, C.A. O'Reilly, J.A. Chatman, Intellectual structure of research in organizational behavior, 1972–1984: a cocitation analysis, J. Am. Soc. Inf. Sci. 41 (6) (1990) 453–458.
[24] H.A. Schildt, Sitkis: Software for Bibliometric Data Management and Analysis, Institute of Strategy and International Business, Helsinki, 2002.
[25] S. Borgatti, M. Everett, L. Freeman, Ucinet for Windows: Software for Social Network Analysis, Analytic Technologies, 2002.
[26] A. Pilkington, C. Liston-Heyes, Is production and operations management a discipline? A citation/co-citation study, Int. J. Oper. Prod. Manag. 19 (1) (1999) 7–20.
[27] M. Amer, T.U. Daim, Application of technology roadmaps for renewable energy sector, Technol. Forecast. Soc. Chang. 77 (8) (2010) 1355–1370.
[28] M.G. Oliveira, H. Rozenfeld, Integrating technology roadmapping and portfolio management at the front-end of new product development, Technol. Forecast. Soc. Chang. 77 (8) (2010) 1339–1354.
[29] R. Phaal, C.J.P. Farrukh, D.R. Probert, Technology roadmapping—A planning framework for evolution and revolution, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 5–26.
[30] R. Phaal, C.J.P. Farrukh, D.R. Probert, Strategic roadmapping: a workshop-based approach for identifying and exploring strategic issues and opportunities, Eng. Manag. J. 19 (1) (2007) 3–12.
[31] J.M. Richey, M. Grinnell, Evolution of roadmapping at Motorola, Res. Technol. Manag. 47 (2) (2004) 37–41.
[32] M. Pagani, Roadmapping 3G mobile TV: strategic thinking and scenario planning through repeated cross-impact handling, Technol. Forecast. Soc. Chang. 76 (3) (2009) 382–395.
[33] A.L. Porter, W.B. Ashton, G. Clar, J.F. Coates, K. Cuhls, S.W. Cunningham, K. Ducatel, P. Duin, L. Georghiou, T. Gordon, H.A. Linstone, V. Marchau, G. Massari, I. Miles, M. Mogee, A. Salo, F. Scapolo, R. Smits, W. Thissen, Technology futures analysis: toward integration of the field and new methods, Technol. Forecast. Soc. Chang. 71 (3) (2004) 287–303.
[34] T. Suomalainen, O. Salo, P. Abrahamsson, J. Similä, Software product roadmapping in a volatile business environment, J. Syst. Softw. 84 (6) (2011) 958–975.
[35] A. Tuominen, T. Ahlqvist, Is the transport system becoming ubiquitous? Socio-technical road-mapping as a tool for integrating the development of transports policies and intelligent transport systems and services in Finland, Technol. Forecast. Soc. Chang. 77 (2010) 120–134.
[36] O. Saritas, M.A. Oner, Systemic analysis of UK foresight results — Joint application of integrated management model and roadmapping, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 27–65.
[37] Y. Yasunaga, M. Watanabe, M. Korenaga, Application of technology roadmaps to governmental innovation policy for promoting technology convergence, Technol. Forecast. Soc. Chang. 76 (1) (2009) 61–79.
[38] W. McDowall, M. Eames, Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: a review of the hydrogen futures literature, Energy Policy 34 (11) (2006) 1236–1250.
[39] C.E. Richardson, R.M. Roop, S. Hendry, M.H. Azarian, S. Ganesan, Sensor technology roadmapping efforts at iNEMI, IEEE Trans. Compon. Packag. Technol. 28 (2) (2005) 372–375.
[40] Y. An, S. Lee, Y. Park, Development of an integrated product-service roadmap with QFD: a case study on mobile communications, Int. J. Serv. Ind. Manag. 19 (5) (2008) 621–638.
[41] K. Donnelly, Z. Beckett-Furnell, S. Traeger, T. Okrasinski, S. Holman, Eco-design implemented through a product-based environmental management system, J. Clean. Prod. 14 (15–16) (2006) 1357–1367.
[42] S. Lee, S. Lee, H. Seol, Y. Park, Using patent information for designing new product and technology: keyword based technology roadmapping, R&D Manag. 38 (2) (2008) 169–188.
[43] T.U. Daim, T. Oliver, Implementing technology roadmap process in the energy services sector: a case study of a government agency, Technol. Forecast. Soc. Chang. 75 (5) (2008) 687–720.
[44] U. Lichtenthaler, Integrated roadmaps for open innovation, Res. Technol. Manag. 51 (3) (2008) 45–49.
[45] J. Amadi-Echendu, O. Lephauphau, M. Maswanganyi, M. Mkhize, Case studies of technology roadmapping in mining, J. Eng. Technol. Manag. 28 (1–2) (2011) 23–32.
[46] J. Elliott, Biometrics roadmap for police applications, BT Technol. J. 23 (4) (2005) 37–44.

[47] N. Gerdsri, R.S. Vatananan, S. Dansamasatid, Dealing with the dynamics of technology roadmapping implementation: a case study, Technol. Forecast. Soc. Chang. 76 (1) (2009) 50–60.
[48] E. Hansis, D. Schafer, O. Dossel, M. Grass, Evaluation of iterative sparse object reconstruction from few projections for 3-D rotational coronary angiography, IEEE Trans. Med. Imaging 27 (11) (2008) 1548–1555.
[49] T. Ma, S. Liu, Y. Nakamori, Roadmapping as a way of knowledge management for supporting scientific research in academia, Syst. Res. Behav. Sci. 23 (6) (2006) 743–755.
[50] J. Lee, C.-Y. Lee, T.-Y. Kim, A practical approach for beginning the process of technology roadmapping, Int. J. Technol. Manag. 47 (4) (2009) 306–321.
[51] I.J. Petrick, A.E. Echols, Technology roadmapping in review: a tool for making sustainable new product development decisions, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 81–100.
[52] M.C. Dissel, R. Phaal, C.J.P. Farrukh, D.R. Probert, Value roadmapping, Res. Technol. Manag. 52 (6) (2009) 45–53.
[53] R.C. McCarthy, Linking technological change to business needs, Res. Technol. Manag. 46 (2) (2003) 47–52.
[54] R. Phaal, G. Muller, An architectural framework for roadmapping: towards visual strategy, Technol. Forecast. Soc. Chang. 76 (1) (2009) 39–49.
[55] H. Abe, T. Ashiki, A. Suzuki, F. Jinno, H. Sakuma, Integrating business modeling and roadmapping methods — The Innovation Support Technology (IST) approach, Technol. Forecast. Soc. Chang. 76 (1) (2009) 80–90.
[56] D. Fenwick, T.U. Daim, N. Gerdsri, Value Driven Technology Road Mapping (VTRM) process integrating decision making and marketing tools: case of Internet security technologies, Technol. Forecast. Soc. Chang. 76 (8) (2009) 1055–1077.
[57] T. Froese, Construction process technologies: a meta-analysis of Canadian research, Can. J. Civ. Eng. 36 (3) (2009) 480–491.
[58] P. Groenveld, Roadmapping integrates business and technology, Res. Technol. Manag. 40 (5) (1997) 48–55.
[59] N. Gindy, M. Morcos, B. Cerit, A. Hodgson, Strategic technology alignment roadmapping STAR® aligning R&D investments with business needs, Int. J. Comput. Integr. Manuf. 21 (8) (2008) 957–970.
[60] B. Yoon, R. Phaal, D.R. Probert, Morphology analysis for technology roadmapping: application of text mining, R&D Manag. 38 (1) (2008) 51–68.
[61] S. Lee, Y. Park, Customization of technology roadmaps according to roadmapping purposes: overall process and detailed modules, Technol. Forecast. Soc. Chang. 72 (5) (2005) 567–583.
[62] I. Nonaka, H. Takeuchi, The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation? Oxford University Press, New York, 1995.
[63] I. Nonaka, R. Toyama, The knowledge-creating theory revisited: knowledge creation as a synthesizing process, Knowl. Manag. Res. Pract. 1 (1) (2003) 2–10.
[64] P.J. Whalen, Strategic and technology planning on a roadmapping foundation, Res. Technol. Manag. 50 (3) (2007) 40–51.
[65] V. Coates, M. Farooque, R. Klavans, K. Lapid, H.A. Linstone, C. Pistorius, A.L. Porter, On the future of technological forecasting, Technol. Forecast. Soc. Chang. 67 (1) (2001) 1–17.
[66] R.R. Cosner, E.J. Hynds, A.R. Fusfeld, C.V. Loweth, C. Scouten, R.E. Albright, Integrating roadmapping into technical planning, Res. Technol. Manag. 50 (6) (2007) 31–48.
[67] R. Phaal, C.J.P. Farrukh, D.R. Probert, A framework for supporting the management of technological knowledge, Int. J. Technol. Manag. 27 (1) (2004) 1.
[68] R. Phaal, C.J.P. Farrukh, D.R. Probert, Technology management tools: concept, development and application, Technovation 26 (3) (2006) 336–344.
[69] J.D. Strauss, M. Radnor, Roadmapping for dynamic and uncertain environments, Re. Technol. Manag. 47 (2) (2004) 51–57.
[70] T. Talonen, K. Hakkarainen, Strategies for driving R&D and technology development, Res. Technol. Manag. 51 (5) (2008) 54–60.
[71] R.E. Albright, T.A. Kappel, Roadmapping the corporation, Res. Technol. Manag. 46 (2) (2003) 31–40.
[72] D. Barker, D.J.H. Smith, Technology foresight using roadmaps, Long Range Plan. 28 (2) (1995) 21–28.
[73] O.H. Bray, M.L. Garcia, Technology roadmapping: the integration of strategic and technology planning for competitiveness, in: Portland International Center for Management of Engineering and Technology — PICMET, 1997.
[74] R. Galvin, Science roadmaps, Science 280 (5365) (1998) 803.
[75] N. Gerdsri, P. Assakul, R.S. Vatananan, An activity guideline for technology roadmapping implementation, Tech. Anal. Strateg. Manag. 22 (2) (2010) 229–242.
[76] R.N. Kostoff, R. Boylan, G.R. Simons, Disruptive technology roadmaps, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 141–159.
[77] R. Phaal, C.J.P. Farrukh, R. Mitchell, D.R. Probert, T-Plan: The Fast-start to Technology Roadmapping — Planning Your Route to Success, Institute for Manufacturing: University of Cambridge, 2001.
[78] R. Phaal, C.J.P. Farrukh, W. Mitchell, D.R. Probert, Characterization of technology roadmaps: purpose and format, in: Portland International Center for Management of Engineering and Technology — PICMET, 2001.
[79] S.T. Walsh, Roadmapping a disruptive technology: a case study, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 161–185.
[80] A. Schwery, V.F. Raurich, Supporting the technology-push of a discontinuous innovation in practice, R&D Manag. 34 (5) (2004) 539–552.
[81] M. Caetano, D.C. Amaral, Roadmapping for technology push and partnership: a contribution for open innovation environments, Technovation 31 (7) (2011) 320–335.
[82] H.I. Christensen, Euron – the European robotics network – Building a stronger robotics research community, IEEE Robot. Autom. Mag. 12 (2) (2005) 10–13.
[83] J. Foden, H. Berends, Technology Management at Rolls-Royce, Res. Technol. Manag. 53 (2) (2010) 33–42.
[84] R. Galvin, Roadmapping—A practitioner's update, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 101–103.
[85] Y. Geum, S. Lee, D. Kang, Y. Park, Technology roadmapping for technology-based product–service integration: a case study, J. Eng. Technol. Manag. 28 (3) (2011) 128–146.
[86] J.M. Goenago-Larranaga, R. Phaal, Roadmapping in industrial companies: experience, DYNA 85 (4) (2010) 331–340.
[87] P. Groenveld, Roadmapping integrates business and technology, Res. Technol. Manag. 50 (6) (2007) 49–58.
[88] B. Hicks, L.H. Riggs, L. McDaniel, J. Sanner, Managing change through roadmapping, IEEE Aerosp. Electron. Syst. Mag. 19 (5) (2004) 9–15.
[89] S.K. Korotky, Network global expectation model: a statistical formalism for quickly quantifying network needs and costs, J. Light. Technol. 22 (3) (2004) 703–722.
[90] S. Lee, S. Kang, Y. Park, Y. Park, Technology roadmapping for R&D planning: the case of the Korean parts and materials industry, Technovation 27 (8) (2007) 433–445.
[91] S. Lee, B. Yoon, C. Lee, J. Park, Business planning based on technological capabilities: patent analysis for technology-driven roadmapping, Technol. Forecast. Soc. Chang. 76 (6) (2009) 769–786.
[92] M.R. Levitt, B.V. Ghodke, D.L. Cooke, D.K. Hallam, L.J. Kim, L.N. Sekhar, Endovascular procedures with CTA and MRA roadmapping, J. Neuroimaging 21 (3) (2011) 259–262.
[93] T. Ma, A.P. Wierzbicki, Y. Nakamori, Establish a creative environment for roadmapping in academy—From the perspective of i-system methodology, J. Syst. Sci. Syst. Eng. 16 (4) (2007) 469–488.
[94] A. McMillan, Roadmapping–agent of change, Res. Technol. Manag. 46 (2) (2003) 40–47.
[95] R. Phaal, C.J.P. Farrukh, R. Mitchell, D.R. Probert, Starting-up roadmapping fast, Res. Technol. Manag. 46 (2) (2003) 52–58.
[96] R. Phaal, E. O'Sullivan, M. Routley, S. Ford, D.R. Probert, A framework for mapping industrial emergence, Technol. Forecast. Soc. Chang. 78 (2) (2011) 217–230.
[97] D.R. Probert, M. Radnor, Technology roadmapping: frontier experiences from industry-academia consortia, Res. Technol. Manag. 46 (2) (2003) 27–30.
[98] M. Radnor, D.R. Probert, Technology roadmapping, Res. Technol. Manag. 47 (2) (2004) 24–37.
[99] O. Saritas, J. Aylen, Using scenarios for roadmapping: the case of clean production, Technol. Forecast. Soc. Chang. 77 (7) (2010) 1061–1075.
[100] A.M. Sorli-Pena, A.J. Urrutia-Bilbao, L.J. Malo-Diez, Development of company's technology plan, DYNA 85 (8) (2010) 687–702.
[101] S.J.M. Bosch, J.C. Brezet, P.J. Vergragt, How to kick off system innovation: a Rotterdam case study of the transition to a fuel cell transport system, J. Clean. Prod. 13 (10–11) (2005) 1027–1035.
[102] A.P.S. Vargas, O.F.C. Domínguez, K.P.D. Martinez, Roadmapping for improving cocoa postharvest management, Rev. Ing. Investig. 28 (3) (2008) 150–158.
[103] B.A. Vojak, F.A. Chambers, Roadmapping disruptive technical threats and opportunities in complex, technology-based subsystems: the SAILS methodology, Technol. Forecast. Soc. Chang. 71 (1–2) (2004) 121–139.
[104] B.A. Vojak, C.A. Suarez-Nunez, Product attribute bullwhip in the technology planning process and a methodology to reduce it, IEEE Trans. Eng. Manag. 51 (3) (2004) 288–299.
[105] B. Wall, H. Jagdev, J. Browne, An approach to developing an eBusiness roadmap, Prod. Plan. Control 16 (7) (2005) 701–715.
[106] Y. Yamashita, Y. Nakamori, A.P. Wierzbicki, Knowledge synthesis in technology development, J. Syst. Sci. Syst. Eng. 18 (2) (2009) 184–202.

[107] R.S. Vatananan, N. Gerdsri, The current state of technology roadmapping (TRM) research and practice, in: Portland International Conference on management of Engineering and Technology (PICMET), Phuket, 2010.
[108] R.G. Cooper, S.J. Edgett, Product Innovation and Technology Strategy, Product Development Institute, 2009.
[109] N. Gerdsri, A. Kongthon, R.S. Vatananan, Mapping the knowledge evolution and network of technology roadmapping (TRM), in: Portland International Conference on management of Engineering and Technology (PICMET), Cape Town, 2008.
[110] V.C. Prieto, M.M. Carvalho, Strategic Alignment and Performance: Brazilian companies in the Medical Diagnostic Sector, The Service Industries Journal. 31 (13) (2011) 1405–1427.

Marly Monteiro de Carvalho She is an associate professor in the production engineering department at the University of São Paulo, Brazil. She is the coordinator of the Project Management Lab. (http://www.pro.poli.usp.br/lgp) and the coordinator of Quality and Product Engineering research group of CNPq (Brazilian Federal Research Agency). She holds a degree in production engineering from the University of São Paulo, M.Sc., a PhD in the same area from the Federal University of Santa Catarina, and a post-doctoral degree from Polytechnic of Milan. Her research interests include project management, innovation management, and quality management.

André Leme Fleury He is an assistant professor at de Polytechnic School of USP, working in undergraduate students of the Department of Production Engineering, since 2008. He has experience in Production Engineering with an emphasis in technology management.

Ana Paula Vilas Boas Viveiros Lopes She is a PhD candidate in the production engineering department from the Polytechnic University of USP. Her research interests include innovation, focusing on the impact of cooperative relationships on the results of the companies. She works as a researcher.