Emerging trends in roadmapping research: A bibliometric literature review

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A Bibliometric Literature Review

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Abstract

Roadmapping practice and research have evolved together over the past three decades, in response to the changing application context, such as the emergence of cutting-edge technologies and rapid social changes. The widespread adoption and adaptation of (technology) roadmapping has been enabled by its simplicity, flexibility and usefulness, reflected in a surge in the volume of literature on roadmapping. A limited number of literature reviews have been conducted, mostly using qualitative and meta-analytical approaches. This paper, however, deploys a quantitative and macro-oriented approach to provide an objective and comprehensive view of the literature by following DNCT procedures, consisting of citation network and text mining analysis. This paper identifies contributing authors, journals and countries, sets out key research themes, and highlights significant developments in roadmapping practice and theory, with reference to previous studies. Results have proven that roadmapping has become an established research topic. Ten clusters of research streams are detected: General Concept & Scenario; Technology Management Tool; Implementation in National and Industrial Levels; Fundamental Research; Implementation in Organizational Level; Innovation Planning; Strategic Planning Synchronization; Strategic Foresight; Industrial Emergence; and Design & Visualization. In addition, an academic landscape of the field is graphically illustrated, and potential avenues for future research are suggested.

Keywords: Roadmapping, Technology Roadmapping (TRM), Bibliometric, Scientometric, Literature Review, Research Topic

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Introduction

Roadmapping practice and research have evolved together over the past three decades, in response to the changing application context, such as the emergence of cutting-edge technologies and rapid social changes (Park et al., 2020). Before formal acknowledgement of roadmapping in academic literature, the use of roadmapping was limited to internal applications within organizations, with limited disclosure due to confidentiality of R&D activities, with first evidence of its use in the 1960s (Kerr and Phaal, 2020). Due to its simplicity, flexibility and usefulness, roadmapping has been widely adopted and adapted in various organizational settings across industries and countries (Vinayavekhin and Phaal, 2019), as reflected by a surge in the volume of literature on roadmapping. To date, a limited number of literature reviews have been conducted, with most of them employing qualitative and meta-analytical approaches (Vatananan and Gerdsri, 2012, Letaba et al., 2015, Choomon et al., 2009, Kostoff and Schaller, 2001, Park et al., 2020, Kerr and Phaal, 2020).

In this paper, we deploy a quantitative and macro-oriented approach, a bibliometric literature review, to provide a rather more objective and comprehensive overview of the literature (Batistič and van der Laken, 2019). Following the DNCT procedures, we combine citation network and text mining analyses to identify contributing authors, journals and countries, set out key research themes, and highlight significant developments in roadmapping practice and theory, with reference to previous studies. Further, an academic landscape of the field is illustrated graphically, and potential avenues for future research are suggested.

Literature Review

Roadmapping is defined as “a process that mobilizes structured systems thinking, visual methods (e.g. roadmap 'canvas') and participative approaches to address organizational challenges and opportunities, supporting communication and alignment for strategic planning and innovation management within and between organizations at firm and sector levels” (Park et al., 2020). Industrial roadmapping practice emerged in the 1960s, three decades before academic interest developed, with use limited to internal applications within organizations such as Boeing, GE, Lockheed, USAF, Rockwell International and the U.S. Department of Energy, with dissemination inhibited by confidentially concerns relating to R&D and strategy. Some of the first documented use cases of roadmapping are from technological-based organizations such as Motorola, Philips, EIRMA, and the Semiconductor Industry Association. Where economic emergence is driven by technology, objectivity and efficacy need to be integrated into the very fabric of organizations (Oliveira and Rozenfeld, 2010). Therefore, roadmapping has become an increasingly popular management process because it incorporates the features to analyze the relationships between markets, products and technologies (de Alcantara and Martens, 2019).

A number of roadmapping literature reviews have been conducted, and most of them deploy qualitative and meta-analytical approaches (Vatananan and Gerdsri, 2012, Letaba et al., 2015, Choomon et al., 2009, Kostoff and Schaller, 2001, Park et al., 2020, Kerr and Phaal, 2020). However, the use of relatively quantitative and macro-oriented literature review approaches is underexplored. Very few papers use bibliometric techniques to analyze the roadmapping literature (de Alcantara and Martens, 2019, Gerdsri et al., 2013, Carvalho et al., 2013). These three papers utilized bibliometric data to quantitatively identify key publications, contributing authors, countries and journals, set out key research themes, and highlight significant developments in roadmapping practice and theory. Carvalho et al. (2013) and Gerdsri et al.

(2013) focused on a broad view of the roadmapping literature by including all papers related to roadmapping, while de Alcantara and Martens (2019) specifically focused on strategic models of roadmapping.

Due to the fact that the number of roadmapping-related literature has exceeded 500 papers as of 13 June 2020, it is time to take another look at the whole body of literature again. The previous studies should be taken into account so that the evolution of roadmapping research is clarified. At the same time, the recent emerging research trends should be reported, and future potential research areas identified.

Methodology

A bibliometric literature review has been adopted as a methodology to review papers in the field of roadmapping. Compared to qualitative and meta-analytical literature review methods, this approach relatively quantitative and macro-oriented, resulting in a more objective and comprehensive view of the literature (Batistič and van der Laken, 2019). We deployed combination of citation network analysis and text mining techniques, adapted from the previous studies (Kajikawa et al., 2014, Asatani et al., 2020, Kajikawa et al., 2007), following the DNCT procedures in four steps: (1) Dataset Construction, (2) Network Construction, (3) Cluster Analysis, and (4) Text Mining.

Step 1: Dataset Construction

We constructed the dataset from the Scopus database, the largest citation and abstract database of peer-reviewed literature, managed by Elsevier publishing. Besides its enriched metadata records of academic papers from over 23,500 peer-reviewed journals, Scopus conducts sophisticated profiling and manual curation to ensure high accuracy and recall of comprehensive author profiles (Baas et al., 2020). The initial search found 994 papers published in English, where the term 'roadmapping' appeared in the title, abstract or keywords. This search strategy is similar to the previous bibliometric study (Carvalho et al., 2013), which avoided searching for the term 'roadmap' as retrieved papers often include papers which are unrelated to the roadmapping method (Letaba et al., 2015, Gerdsri et al., 2013). To ensure quality, we restricted the search to only papers published in peer-review journals, resulting in 503 papers. We then downloaded bibliographical information including title, author, affiliation, country, abstract and keywords from the Scopus database on 13 June 2020.

Step 2: Network Construction

After constructing the dataset, we conducted the citation network analysis using graph theory to explore the data structure (Lewis-Beck et al., 2004). Each paper was represented as a node, with its citation relationships represented by links. Papers not citing, nor cited by any other download papers, were excluded as being irrelevant or not belonging to the mainstream research (Kajikawa et al., 2007). Thus, we focused only on the maximum connected network of 281 papers. We conducted the initial analysis by using simple statistical measures to explain trends in roadmapping literature such as the number of papers and years of publication. In addition, we also identified contributing authors, journals and countries.

Step 3: Cluster Analysis

We then grouped papers into clusters by applying the Louvain clustering algorithm to the citation network. This algorithm determines the best cluster set based on the maximized value of the modularity Q (Blondel et al., 2008). Each cluster representing a group of well-connected papers in the same research area was visualized by a large graph layout method (Adai et al., 2004). The intra-cluster links were highlighted in the same color in order to identify the structure, shape, and position of each cluster (Kajikawa et al., 2014). We also used simple statistical measures to identify influential papers, top main journals and contributing authors for each cluster.

Step 4: Text Mining

In addition to the cluster analysis, we utilized text mining techniques to analyze the actual words written by the authors in the title and abstract of each paper, aiming for an objectively content-driven literature review (Biesenthal and Wilden, 2014). We used natural language processing to extract terms from each paper, while avoiding non-term sequences of words and duplications of singular and plural words (Loper and Bird, 2002, Califf and Mooney, 1999). Next, we adopted a term-scoring method to rank the representative terms for each cluster by calculating the TFIDF value, the multiple of the term frequency (TF) and the inverse document frequency (IDF) (Sparck Jones, 1972, Aizawa, 2003). Higher TFIDF values mean higher common uniqueness among the papers in the same cluster. In combination with the co-citation network analysis, it was possible to empirically structure knowledge within the roadmapping literature.

Result and Discussion

Initial Analysis

Publication Trend

On average, 17.3 papers were published annually between 2011 to 2019, up from 11.4 papers in the previous decade, ranging from 10 to 23 papers (Figure 1). This represents an increase in the number of papers compared to a previous analysis by Gerdsri et al. (2013) of 137 papers submitted to journals and conferences. Despite fluctuation in the number of papers over the years, there is an upward trend.

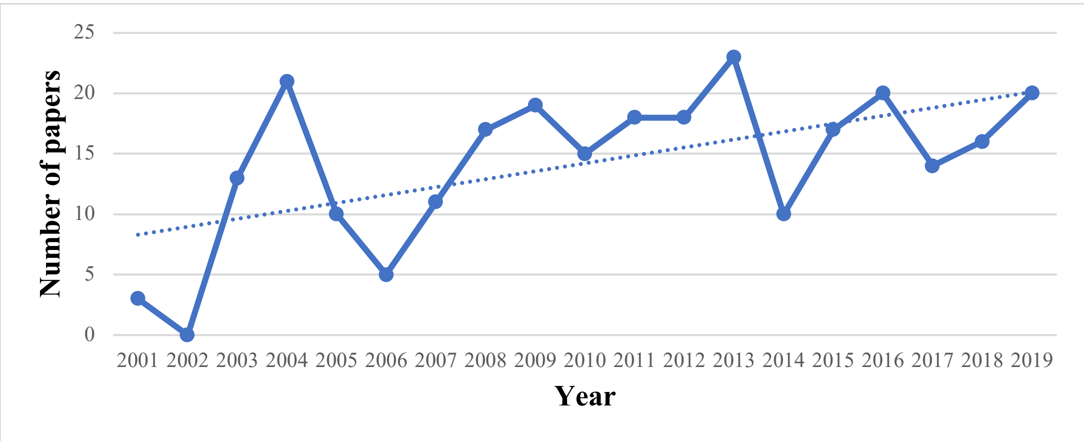


Figure 1 Publication trend

Contributing Affiliation and Author

Regarding affiliations, the UK and the USA are the most prolific in terms of publications (Figure 2). Similarly to the study by de Alcantara and Martens (2019), the UK remains the country with the largest proportion of contributors to roadmapping studies. The majority of these works are contributed by Kerr and Phaal from the University of Cambridge. While the USA ranked highest in 2013 (Gerdsri et al., 2013), it is now in the second position. On the other hand, Japan dropped from the third to be the ninth, and South Korea, Germany, China, and Thailand each moved up one position.

The top 10 contributing authors are consistent with the number of publications per country and accounted for 20.3% of total papers written as of 2020. Compared to the previous analysis (Gerdsri et al., 2013), Porter and Meissner have become the new leading authors.

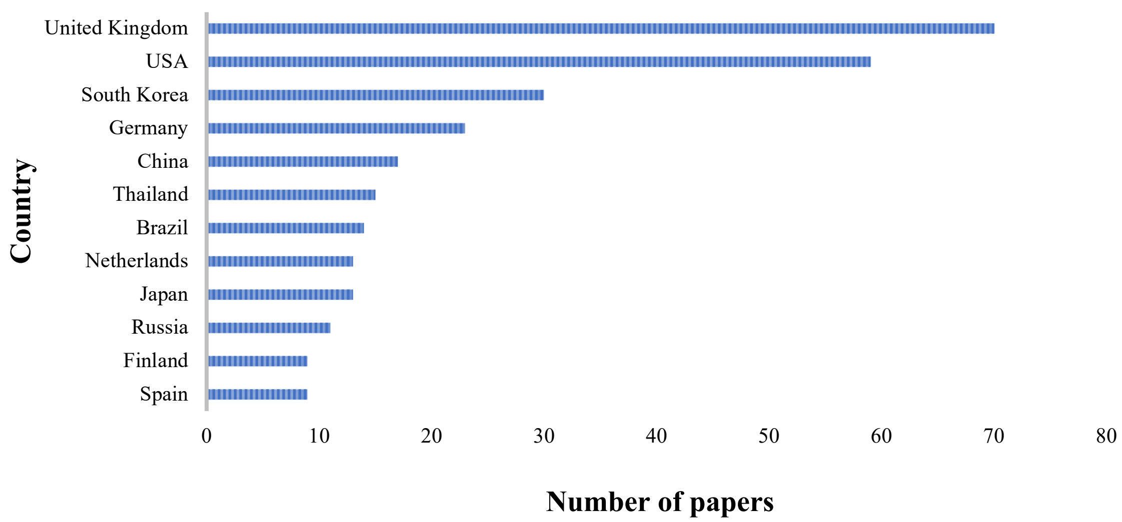


Figure 2 Number of publications per country (N>=5)

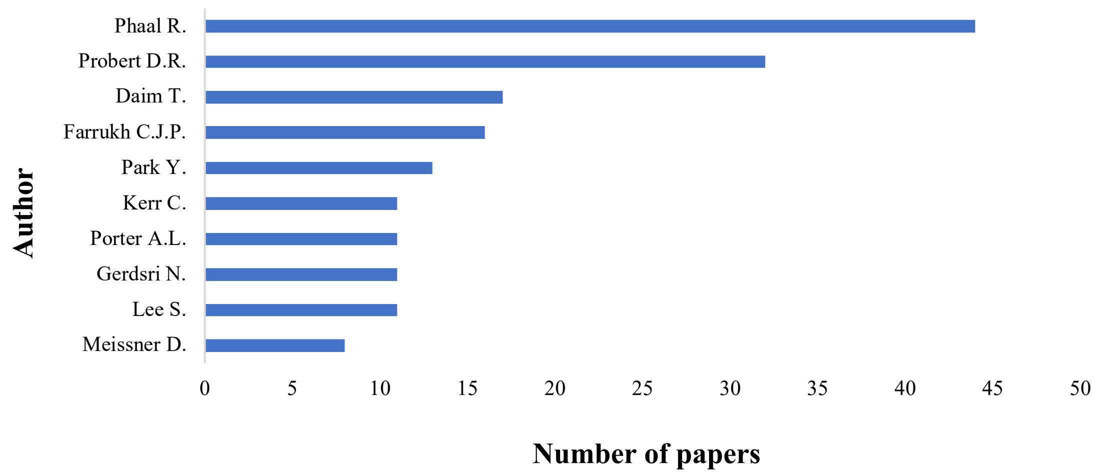


Figure 3 Contributing authors (N>=6)

Contributing journal

Two major journals, Technological Forecasting and Social Change (N=70) and Research Technology Management (N=23), have a large proportion of roadmapping publications, accounting for 33% of the total papers (Figure 4). The former journal has consistently published academic papers in this field since 2001. The latter practitioner-oriented journal, which has been ranked as a top journal in Gerdsri et al. (2013)'s analysis, is recently less active in this field as 91% (N=22) of papers were published before 2010. The top journals with a sharp increase in the recent years are Technology Analysis and Strategic Management (N=14), International Journal of Innovation and Technology Management (N=12), and Journal of Engineering and Technology Management (N=11), respectively.

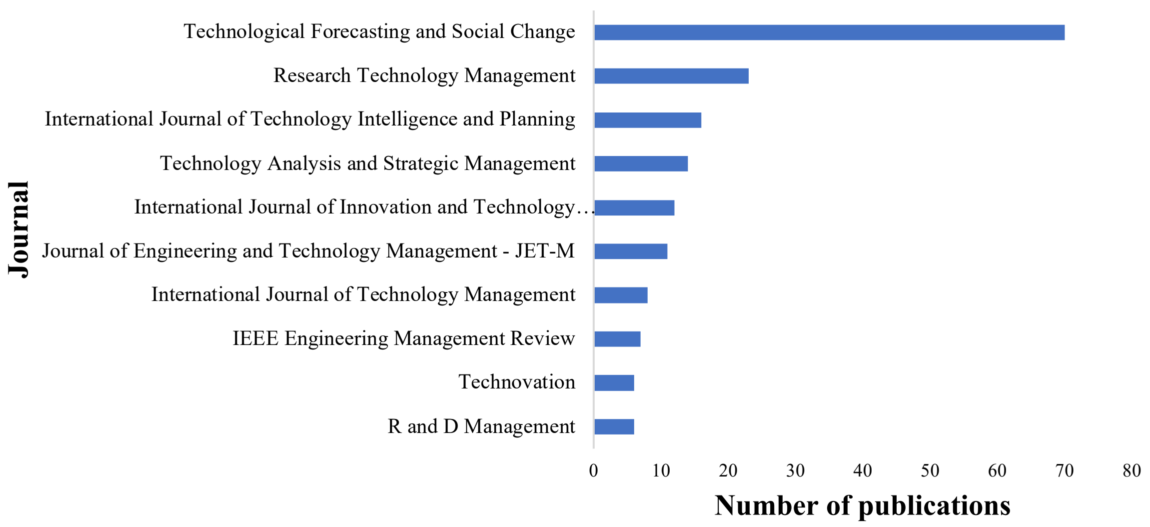


Figure 4 Contributing journals (N>=6)

Cluster Analysis and Text Mining Analysis

As of June 2020, the maximum connected network of 281 papers can be categorized into 10 clusters, with the number of nodes in each cluster varying from 10 to 48. According to **Error! Reference source not found.** and Table 1, pattern and contents of each cluster can be summarized briefly as followed.

Cluster #1 General Concept & Scenario

Cluster #1 is the General Concept & Scenario cluster, which has the largest number of 48 papers and is prominently positioned in the citation network. Groenveld (1997) provided a powerful conceptual direction for roadmapping in terms of integrating business strategy, describing the "product-technology roadmapping process developed at Philips Electronics, which aimed at better integration of business and technology". Albright and Kappel (2003b) identified areas of improvement for roadmapping activities in business entities, based on experience at Lucent Technologies in the early 2000s. Recent works in this cluster concern scenario-based roadmapping, building on the early publication by Strauss and Radnor (2004) suggesting the combination of roadmapping and scenario planning.

The enhancement of scenario-based roadmapping is a prominent area for the future research. The variety of methodology for developing scenario-based roadmapping is still low. Furthermore, the layers of roadmaps associated with the external environment encompass highly uncertain scenarios relating to highly dynamic external environments, whereas resource-oriented layers deal with relatively controllable internal factors. Lee and Geum (2017) proposed a novel methodology using Cross Impact Analysis (CIA) and the Analytical Hierarchy Process (AHP), and Son et al. (2020) introduced a framework to develop scenario-based roadmapping using fuzzy cognitive mapping and text mining to analyze big data.

Cluster #2 Technology Management Tool

Cluster #2 is the Technology Management Tool cluster, in which the role of roadmapping in technology management is discussed. A literature review by Kostoff and Schaller (2001) dominates the cluster. Phaal (2004) discussed the context of roadmapping in technology strategy and technology transitions in which the tool "providing a focus for scanning the environment and a means of tracking the performance of individual, including potentially disruptive, technologies". Phaal et al. (2006) discussed four generic types of technology management tools, namely matrices, grids, tables, and scored profiles, and proposed integrating these tools in roadmapping processes for strategic technology management.

Future research focuses on integrating novel technology management techniques with roadmapping. Lahoti et al. (2018) proposed technology mining techniques using R&D data to validate and refine roadmapping content in order to reduce the dependency on experts. Contreras-Medina et al. (2019) conducted a study with 171 indigenous coffee producers in Mexico and developed a technology roadmap based on knowledge management literature. Westling et al. (2019) developed an Adaptive Planning Process for reflexive adaptive management in UK water services using the integration of three workshops: aspiration, scenario and roadmapping.

Cluster #3 Implementation in National and Industrial Levels

Cluster #3 is the Implementation in National and Industrial Levels cluster, in which the implementation of roadmapping in various industries is illustrated. The study of roadmapping customization using modularization method by Lee and Park (2005) is a leading paper in this cluster. Other papers extended the scope of roadmapping within organizations to cover higher levels of analysis. Amer and Daim (2010) identified three levels of roadmapping: organizational, industry/sector and national levels. The papers in this cluster focus especially on roadmapping at the industrial level, including but not limited to the energy services sector (Daim and Oliver, 2008), the parts and materials industry (Lee et al., 2007), the renewable energy sector (Amer and Daim, 2010), and the public sector (Yasunaga et al., 2009).

Solving macro-level uncertainty remains the future research position. Due to increasing complexity, the implementation of roadmapping at inter-ministry and supply chain levels is an emerging topic in this cluster. On the one hand, Kim and Choi (2018) studied the implementation of roadmapping in inter-ministry R&D strategic planning in Korea. They developed roadmapping processes to solve the problem of missing linkages between ministry departments and national goals. As a result, roadmapping can be used to help to re-design selection criteria of target technology, and build technology-supporting measures to support R&D strategic planning. On the other hand, Dowsett et al. (2019) focused on supply chain integration issues. They utilized the roadmapping framework to study the consequence of supply chain integration in small housebuilders adopting modern methods of construction (MMCs). Using samples from Southeast England, they focused roadmapping at the national level by re-positioning small housebuilders to address the shortfall in housing.

Cluster #4 Fundamental Research

Cluster #4 is the Fundamental Research cluster, in which contributions, trends and evolution of roadmapping are discussed. The paper by Carvalho et al. (2013) dominates the cluster. They conducted a bibliometric review to analyze fundamental aspects of roadmapping, such as advantages and limitations of the method, process phases, and conditions necessary for high-quality roadmapping. However, they reviewed only literature between 1997 to 2011 and focused on technological forecasting and technological development in alignment with the emergence of two major journals in roadmapping studies at that time: Technology Forecasting and Social Change and Research-Technology Management. Other papers include studies on the early implementation of roadmapping such as at Motorola (Richey and Grinnell, 2004), and at General Motors (Grossman, 2004).

Apparently, the research papers in this paper are relatively old, as the average year of publication is 2009. This calls for an updated literature review to identify the recent trends in roadmapping research. Our bibliometric review paper belongs to this cluster, providing updated information in this area of research, including but not limited to publication trends, influential authors, contributing journals and recent trends of research on roadmapping.

Cluster #5 Implementation in Organizational Level

Cluster #5 is the Implementation in Organizational Level cluster, in which the implementation of roadmapping at the organizational level is studied. Gerdsri et al. (2019) focused on a challenge that organizations face in keeping roadmaps 'alive', and developed a decision support model to determine the status of roadmapping. Groenveld (2007) found the benefit of roadmapping for an organisation is to build vision which entails a clear shared product-technology strategy and product-technology planning.

The recent paper by Chutivongse and Gerdsri (2020) proposed an analytical approach for roadmapping in guiding organizational development, and suggested that future research should be conducted to assess the effectiveness of each activity in fostering innovation. Another important topic is the customization of roadmapping to fit specific circumstances of each organization. Kerr et al. (2019) suggested future research should focus on fulfilling two knowledge gaps: customized frameworks for better-fit implementation, and know-how for continuous improvement after receiving feedback.

Cluster #6 Innovation Planning

Cluster #6 is the Innovation Planning cluster, in which key principles, trends and applications of roadmapping in innovation planning are examined. The top five papers with highest within-cluster links were all written by Phaal, and the paper that dominates the cluster is Phaal et al. (2004a)'s paper. A paper entitled "Next generation Roadmapping for innovation planning" (Phaal et al., 2008) proposed that roadmapping needs to be agile, responsive, scalable and flexible.

The latest trend is to deconstruct the complexity of technological innovations and establish standardized processes of innovation planning. Kerr and Ford (2018) proposed roadmapping as a visualization process for communication to support decision making by stakeholders in project management. Ho and O'Sullivan (2018) proposed a standardized roadmapping framework to help with prioritizing and making a long-term and system-wide decisions. Future research should include different types of stakeholders, diverse geographical areas and various roles of organizations in standardization processes.

Cluster #7 Strategic Planning Synchronization

Cluster #7 is the Strategic Planning Synchronization cluster, in which the usage of roadmapping for synchronizing strategic planning is discussed. This cluster is the oldest cluster as nine out of 19 papers were published between 2003 to 2006. These papers have shown that synchronized roadmaps can help a firm in identifying common needs and supporting collaboration across functions (Albright and Kappel, 2003a, McMillan, 2003, McCarthy, 2003). Recent studies include two papers aiming to adopt roadmapping in order to improve synchronization within strategic planning. Vinayavekhin and Phaal (2019) identified four types of synchronization, relating to a focus within-function, within-business-unit, across-business-units and for corporate planning. Vinayavekhin and Phaal (2020) then differentiated synchronization from alignment and integration, as it has time as an explicit dimension, proposing key enablers and a Synchronization Assessment Framework (SAF) as a practical guideline for companies, leveraging the identified critical factors for synchronization processes.

As most research in this cluster has focused on strategic planning synchronization in manufacturing sectors, future research should utilize case studies from non-manufacturing sectors to fulfil the limitation of current research. Research scope should be extended to include the implementation and maintenance phases of strategic planning synchronization as well.

Cluster #8 Strategic Foresight

Cluster #8 is the Strategic Foresight cluster, in which applications of operations, technology and strategic foresight are discussed. Case study illustrations within the cluster are from diverse countries. Holmes and Ferrill (2005) identified and selected emerging technologies for Singaporean small and medium sized enterprises. Vishnevskiy et al. (2015) developed a specific strategic foresight approach and integrated it into roadmapping in the Russian context, and Gershman et al. (2016) surveyed state-owned enterprises (SOEs) and demonstrated that roadmapping can effectively serve as a basis for strategic foresight processes, despite the number of constraints regarding specific conditions of SOEs and their structures.

Recent research in this cluster includes the development of roadmapping for regional foresight, which acts a bridge connecting national and corporate foresight (Kindras et al., 2019). The gap between macro and micro foresight is still a missing piece of knowledge for both researchers and policymakers. Moreover, the studies of strategic foresight are normally conducted in developed countries as they often have sufficient resources with high capabilities. Further research is needed to explore the development of strategic foresight in developing countries.

Cluster #9 Industrial Emergence

Cluster #9 is the Industrial Emergence cluster, in which landscapes of emerging technology-based industries are studied, such as wind, solar and other types of renewable energy. This is the newest of ten cluster, as half of the papers were written between 2015 to 2019. Phaal et al. (2011) provided the foundation by utilizing the concept of industrial lifecycle and roadmapping to study historical industrial emergence. Li et al. (2015) and Li et al. (2016) identified three key issues for technology-oriented emerging industries in China, namely “the significant capability gaps to catching-up in innovation”, “the future external environment factors that may influence the innovation gaps”, and “the strategic development pathways that reduce these gaps”.

Future research is required to explore the emerging technology-based industries in other technology-follower countries, especially in fast-growing economies such as India, Mexico, Indonesia and Brazil.

Cluster #10 Design & Visualization

Cluster #10 is the Design & Visualization cluster, in which the design and visualization of roadmaps are discussed. Kappel (2001) identified four types of roadmaps based on their emphasis and purpose: product-technology, science/technology, industry and product roadmaps. Each type of roadmap requires a different design and should be visualized differently to specifically serve the emphasis and purposes of each roadmap type. Kerr and Phaal (2015) emphasized that the roadmap’s visual form is a strong enabler for effective communication of shared goals and visions among different stakeholders. Many papers in this cluster demonstrate the usage of roadmapping as a strategic visual tool in various organizations such as the Royal Australian Navy (Kerr et al., 2014), a technology-based firm (Bengtsson and Lindkvist, 2017), and software product or service development firms (Suomalainen et al., 2011).

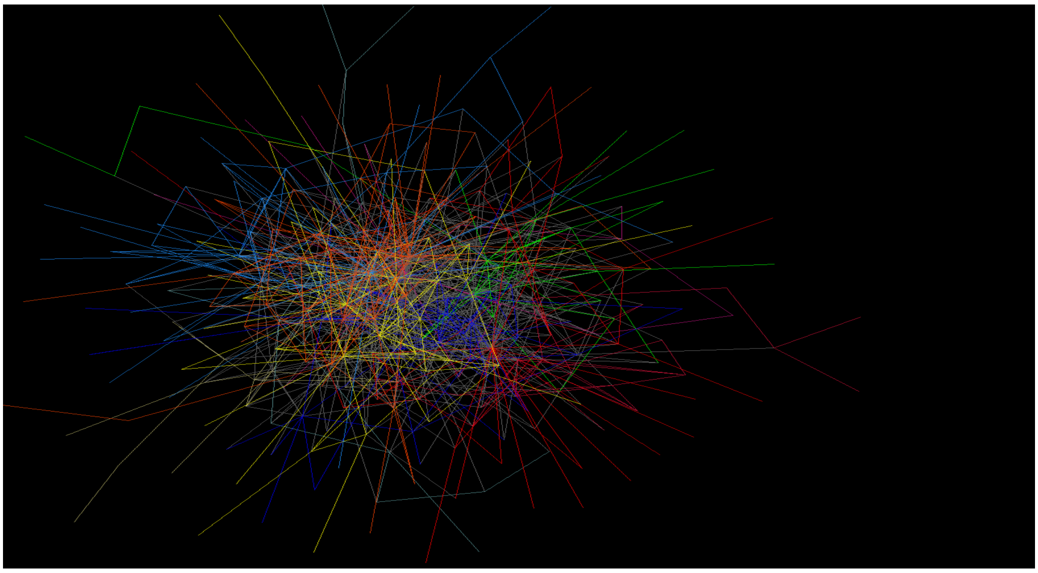
According to Kerr and Phaal (2015), researchers and practitioners usually overlook the importance of the design and visualization of roadmaps. A design-driven approach is the area that requires further enhancement because the approach can help exploit roadmap visualization by providing methodologies for concept development processes. Future research should focus on developing the application of graphic design principles and the execution of the visual aspects of the presentation to ensure the effectiveness of the use of roadmapping as a communication tool.

Table 1 Summary of 10 clusters and their information

Cluster No.	**#Node**	**Average Year**	**Top 3 Papers (With-in Cluster Links)**	**Top 10 Terms from TFIDF Analysis**
#1	48	2011.0	(Groenveld, 1997)* (24) (Albright and Kappel, 2003b) (13) (Strauss and Radnor, 2004) (10)	Scenario, Product, Analysis, Scenario Based, Service, Planning, Decision, Uncertainty, Technology planning
#2	39	2012.2	(Kostoff and Schaller, 2001) (23) (Phaal, 2004) (11) (Lahoti et al., 2018) (10)	Mining, Disruptive, Disruptive Technology, Innovation, Disease, System, Science, Hydrogen, Data, Policy

#3	39	2012.7	(Lee and Park, 2005) (15) (Daim and Oliver, 2008) (12) (Lee et al., 2007) (10)	Energy, Banking, Service, Social Banking, Patent, Scenario, TRM, Roadmap, Social, Technology roadmap
#4	35	2009.5	(Carvalho et al., 2013) (18) (Richey and Grinnell, 2004) (6) (Phaal et al., 2004b) (6)	Hydrogen, Transportation, Space, Space Transportation, Decision, Scenario, System, business, transportation system, creative
#5	34	2012.2	(Gerdsri et al., 2019) (11) (Groenveld, 2007)* (10) (Vatananan and Gerdsri, 2012) (10)	TRM, Organization, Innovation, Strategy, Subsystem, Business, ICT, Implementation, Standardization, Factor
#6	24	2011.8	(Phaal et al., 2004a) (12) (Phaal and Muller, 2009) (9) (Phaal et al., 2008) (5)	Innovation, Battery, Smartphone, User, Standardization, Brazil, Technology Foresight, Framework, Ion, Lithium
#7	19	2009.3	(Vinayavekhin and Phaal, 2019) (8) (Vinayavekhin and Phaal, 2020) (8) (Albright and Kappel, 2003a) (4)	Business Model, Synchronisation, Network, Saving, Energy Saving, Model, Energy, Residential, Evolutionary, Residential Energy
#8	16	2012.4	(Holmes and Ferrill, 2005) (6) (Vishnevskiy et al., 2015) (4) (Lee et al., 2009) (3)	Foresight, Sti, Policy, Assessment, Risk Assessment, Regional, Risk, Sti Policy, Regional Foresight, Innovation
#9	14	2014.0	(Li et al., 2015) (6) (Li et al., 2016) (5) (Phaal et al., 2011) (3)	Energy, Solar, Patent, Emerging, Keyword, Science, Cell, Bibliometrics, OLED, Technological Learning
#10	13	2013.3	(Kappel, 2001) (9) (Kerr and Phaal, 2015) (3) (Kerr et al., 2014) (2)	Design, Design Roadmap, Product Roadmap, Public Sector, Visual, Production, Continuous Planning, Software Product, Software, Product

* It should be noted that Groenveld (2007) is a reprint version of Groenveld (1997) with the slight changes and added page. As these two papers are not identical and researchers cite either or both, we decided not to merge these two papers.



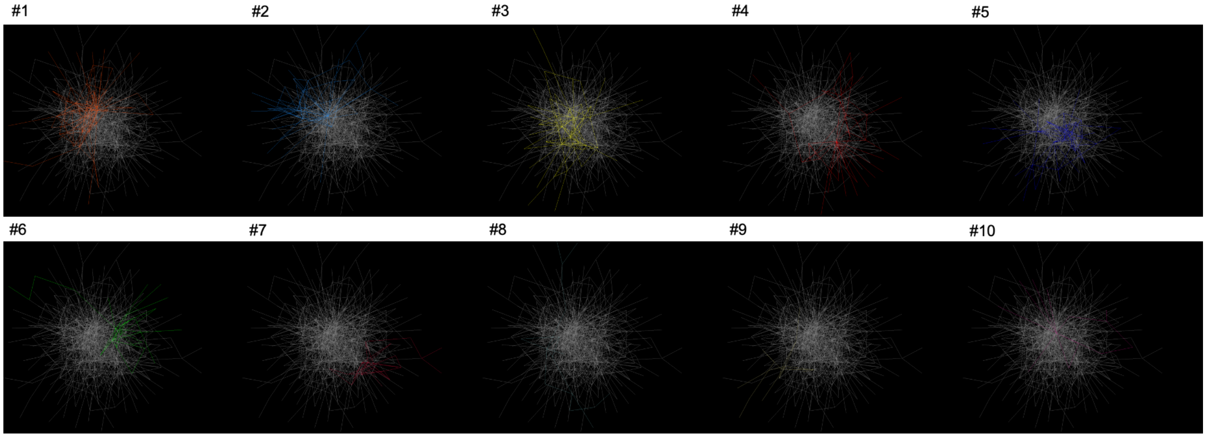


Figure 5 Visualization of the structure of roadmapping research

By considering top 10 terms from TFIDF analysis, some terms are commonly mentioned across clusters. For example, the term 'innovation' is commonly found in Cluster #2, #5, #6, and #8. Due to the high complexity and non-unified definition of the term, Cluster #2 saw innovation as disruptive technologies (e.g., nanotechnology and solar cell), Cluster #5 and #6 together discussed innovation planning at organizational level, and Cluster #8 focused on forward-looking innovation though foresight processes. Besides, the term 'scenario', which belongs to Cluster #1 General Concept & Scenario Planning, is also found in Cluster #3 and #4, as scenario planning is widely used especially in national and industrial levels. This finding demonstrates a close link between roadmapping and scenario planning (Strauss and Radnor, 2004). Furthermore, Cluster #3 and #9 mentioned the term 'patent'. Papers in Cluster #3 discussed about patent roadmap, aiming to "reveal patent competition and support patent strategic decision"(Yu and Zhang, 2019), while papers in Cluster #9 used patent analysis to identify technological gaps and then used roadmapping for formulating strategy for countries which are catching up to the technological frontier (Li et al., 2015, Li et al., 2016).

Conclusion

The existing body of roadmapping research is objectively explored through identifying influential authors, affiliations and journals, and conducting network analysis of citation data and text mining of paper abstracts. Results from this study have shown that roadmapping has become an established research topic.

Regarding the initial analysis, an average of 17.3 papers were published annually between 2011 to 2019, an increase by 37% in comparison to the previous decade. Compared to 2013 (Gerdsri et al., 2013), the UK still contributes the largest proportion of publications. This is followed by the USA and South Korea respectively. Technological Forecasting and Social Change is considered the most active journal for academic publication. Although Research-Technology Management is also recognized for its contribution to the field, few roadmapping papers have been published in the past decade. In terms of main contributing authors, the top three authors are Phaal, Probert and Daim, associated with 44, 32 and 17 publications, respectively.

By implementing cluster analysis and text mining techniques, ten clusters of research streams have been detected with a maximum connected network of 281 papers. Summaries of each cluster are as follows:

1. *General Concept & Scenario* focuses on the general concept of roadmapping in integrating business strategy with technology strategy. The recent research focus is scenario-based roadmapping, which its enhancement is suggested as a future research area.
2. *Technology Management Tool* considers roadmapping as a technology management tool. The future research area of this cluster is the integration with other technology management techniques such as technology mining.
3. *Implementation in National and Industrial Levels* aims to illustrate roadmapping implementation at the macro level. The implementation of roadmapping in inter-ministry and supply chain levels are emerging topics in this cluster.
4. *Fundamental Research* explores contributions, trends and evolution of roadmapping. This bibliometric paper also belongs to this cluster.
5. *Implementation in Organizational Level* focuses on research and practices of roadmapping implementation in any kind of organization. Recent papers include the assessment of activities and the customization of roadmapping.
6. *Innovation Planning includes* key principles, trends and applications of roadmapping in innovation planning are examined. The latest trend and direction of innovation planning is to deconstruct the complexity of technological innovations and standardize innovation planning.
7. *Strategic Planning Synchronization* discusses the differences between integration, alignment and synchronization in strategic planning, and the contribution of roadmapping in these areas. Future research should explore how to utilize roadmapping to implement and maintain firms' strategic planning synchronization.
8. *Strategic Foresight* focuses on the applications of operations, technology and strategic foresight methodology. Bridging the gap between macro and macro foresight, for example, national and corporate foresight, could be further explored.
9. *Industrial Emergence* includes the landscapes of emerging technology-based industries, for example: wind, solar and other types of renewable energy are studied. Future research may explore emerging technology-based industries in technology-follower countries, especially in fast-growing economies such as India, Mexico, Indonesia and Brazil.
10. *Design & Visualization* considers the design and visualization of roadmaps and templates. One direction for future research is to develop the application of graphic design principles and the execution of the visual aspects of the presentation to ensure the effectiveness of roadmapping as a communication tool.

This research is not without limitations. Firstly, this paper included only articles published in peer-review journals to ensure that papers of high quality are included and citations are consistent. Thus, articles from other sources such as books and conferences are not included in the analysis. Secondly, the citation network analysis relies on the assumption of direct citation that a paper directly cites another paper implies similarly. Further study can be pursued by comparing the results from this paper with the results from co-citation and bibliographic coupling analyses. Other techniques such as keyword co-occurrence network analysis can also be used in combination to compare the similarities and differences between findings (Ciano et al., 2019). Lastly, this paper aims to provide quantitative and objective views of roadmapping literature, yet the interpretation of the results is subject to the researchers' prior knowledge and experiences.

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