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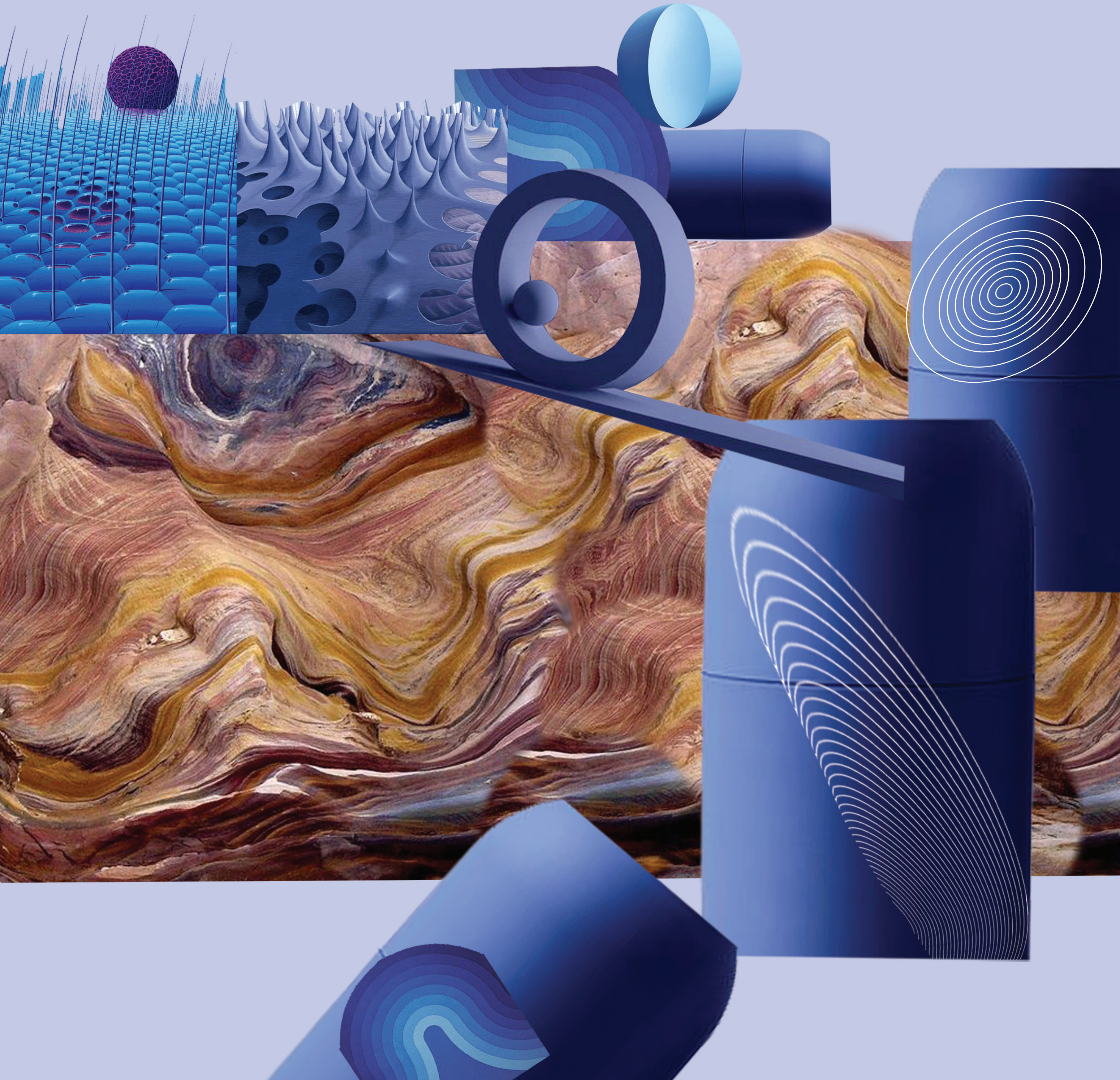
SPECIAL ISSUE

FORESIGHT AND ROADMAPPING METHODOLOGY



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Foresight and STI Governance is an international interdisciplinary peer-reviewed open-access journal. It publishes original research articles, offering new theoretical insights and practice-oriented knowledge in important areas of strategic planning and the creation of science, technology, and innovation (STI) policy, and it examines possible and alternative futures in all human endeavors in order to make such insights available to the right person at the right time to ensure the right decision.

The journal acts as a scientific forum, contributing to the interaction between researchers, policy makers, and other actors involved in innovation processes. It encompasses all facets of STI policy and the creation of technological, managerial, product, and social innovations. *Foresight and STI Governance* welcomes works from scholars based in all parts of the world.

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- Innovative strategies at the national, regional, sectoral, and corporate levels;
- The development of National Innovation Systems;
- The exploration of the innovation lifecycle from idea to market;
- Technological trends, breakthroughs, and grand challenges;
- Technological change and its implications for economy, policy-making, and society;
- Corporate innovation management;
- Human capital in STI;

and many others.

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SPECIAL ISSUE

"FORESIGHT AND ROADMAPPING METHODOLOGY"

Foresight and Roadmapping Methodology: Trends and Outlook

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Abstract

This guest editorial article introduces the contextual and theoretical frameworks of foresight and futures studies' methodologies. Outstanding questions relating to methodological development are then addressed. This is followed by an introduction to five papers that make important methodological contributions. The article ends with a call for further research on the questions that have been identified but remain unanswered.

Keywords: futures; foresight; methodology; roadmapping; scenario; forecasting

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There is a growing need to support strategic decision-making in governments and organizations that consider future uncertainties. The field of futures and foresight[1] [*Glenn, Gordon*, 2009; *Popper,* 2008a,b] include, but is not limited to backcasting, Delphi, forecasting, roadmapping, and scenarios. The application of these methods in Science, Technology, and Innovation (STI) policy is utilized globally [*Miles,* 2010]. Each method provides a structured way of collecting information and generating knowledge about the future as opposed to either guessing or gazing into a crystal ball or predicting the future through a black box [*van der Duin,* 2016]. Other reviews of relevant methods are provided elsewhere [*Bishop et al.,* 2007, *Glenn,* 2009b; *Gordon et al.,* 2020; *Popper,* 2008a,b].

Historically the field of futures and foresight has been led by practitioner-focused approaches, with comparatively little effort given to theory and methodology development [*Fergnani, Chermack,* 2021; *Kishita et al.,* 2021; *Wilkinson,* 2009]. Unlike the natural sciences, there is tremendous variance in methods and tools. There is less systematization on futures and foresight processes and activities (e.g., how to choose an appropriate method to address the problem being considered). Nonetheless, the value of theory is acknowledged in the futures and foresight community. For both a fundamental understanding and to encourage the adoption and implementation of these approaches, the wide dissemination of these futures and foresight methods should be facilitated in society to efficiently train people who are less experienced but want to use such methods in practice.

The fundamental questions raised in this issue are: (1) What methods are the state-of-the-art and (2) what challenges need to be tackled to advance methodology development? This article reviews selected futures and foresight methods, particularly focusing on forecasting, scenarios, and roadmapping. A framework for a better understanding of generalized futures and foresight processes is provided to formulate research questions to further the development of theory and methodology. Finally, how the five papers that constitute this special issue contribute to methodological development is considered.

This section focuses on the methods most typically utilized: scenarios, forecasting, roadmapping, and backcasting.

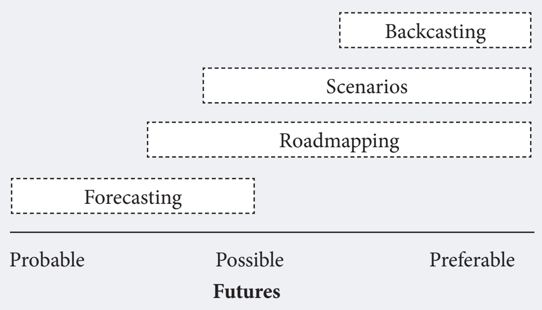
Taxonomy of Futures

Summarizing from different taxonomies, futures can be classified as follows [*Börjeson et al.,* 2006, *Hancock, Bezold,* 1994; *Voros,* 2003]:

- *Probable futures*: refer to futures that are likely to happen by extrapolating current trends.
- *Possible futures*: refer to the widest range of futures that might happen based on currently available knowledge

[1] The term *futures and foresight* includes foresight, futures studies, futures research, and futurology.

Figure 1. **Matching types of futures and foresight methods**

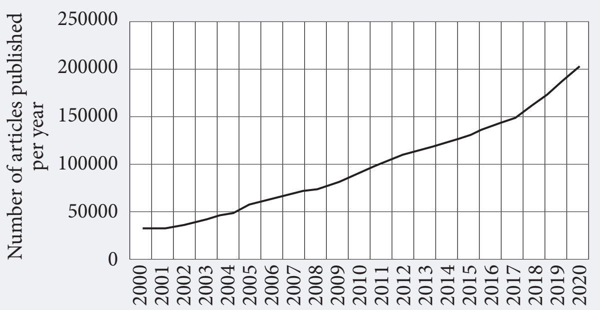


Source: compiled by the author.

and people's imagination (i.e., new knowledge about the future). Considered as part of possible futures, *plausible futures* refer to futures that could happen based on currently available knowledge about the future. *Preferable futures*: refer to normative futures that are desired based on individual and collective values.

As depicted in Figure 1, different methods are chosen depending on which type of future is considered [*Popper,* 2008a; *van der Duin,* 2016]. Forecasting centers on predicting the most likely future. Roadmapping cuts across all types of futures as it emphasizes a process to describe pathways to any kind of future. Scenarios deal primarily with possible and preferable futures because scenarios are not predictions. It should be mentioned that scenarios may include probable futures often described as either baseline or Business-as-Usual (BaU) scenarios. Backcasting describes normative futures including preferable futures and sometimes dystopian or collapsed futures.

Figure 2. **Number of articles published in the period of 2000-2020, with "foresight" or "futures" in their titles, abstracts, or keywords**



Source: mpiled by the author based on Scopus search 20 March 2021.

Key Futures and Foresight Methods

A Scopus search for the words "foresight" or "futures" in article titles, abstracts, or keywords referenced approximately 200,000 articles in 2020. This is six times larger than the number of articles in 2000 (Figure 2). Figure 3 summarizes the articles into four categories: "scenarios," "forecasting," "roadmap or roadmapping," and "backcasting". In 2020, articles about scenarios account for approximately 5% (~10,000) of the total number (~200,000) and those about forecasting come second (approximately 3%). In contrast, fewer articles about roadmapping and backcasting are found. The number of roadmapping articles published in 2020 reached around 700, increasing 10 times from the number in 2000. Backcasting articles increased after the mid-2000s but are still minor in terms of the number of published articles (~30 in 2020).

Forecasting

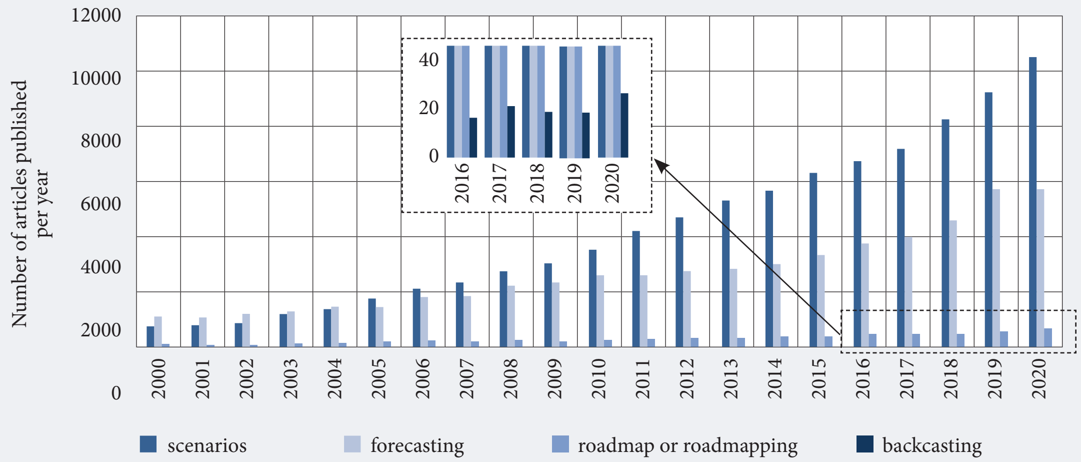
Forecasting consists of both qualitative and quantitative methods. The former includes the Delphi method and text mining. The latter includes trend extrapolation and econometric methods [*Armstrong,* 2001; *Glenn,* 2009b; *Martino,* 1993; *Popper,* 2008a]. Forecasting methods may focus on technology forecasting [*Gerstenfeld,* 1971; *Martino,* 1993]. A brief review of the most frequently used forecasting methods - Delphi method and trend extrapolation - is provided.

The Delphi method. Originally developed for military operations by RAND in the 1950s, the Delphi method is a useful way of assessing expert judgment[2]. Respondents (experts) are independently interrogated using questionnaires iteratively (e.g., two or three rounds), aimed at reaching a consensus on future technological developments [*Linstone, Turoff,* 1975; *Gordon,* 2009]. The selection of respondents is the key to a successful Delphi study [*Gordon,* 2009]. Over the last fifty years, the method has been used by many academics and practitioners [*Rowe, Wright,* 2011]. Since 1969, Japan has utilized large-scale Delphi surveys involving experts in a wide range of fields to support science and technology policy governance [*Kuwahara,* 1999; *Kuwahara et al.,* 2008]. Urashima et al. [*Urashima et al.,* 2012] reviewed the results of the Delphi surveys conducted between 1971 and 1992. They found that approximately 70% of the topics under review had been achieved. The Delphi method is often combined with other techniques. For example, enhancing insights into scenarios [*Wright et al.,* 2013]. This includes the work by [*Chen et al.,* 2020; *Culot et al.,* 2020; *von der Gracht, Darkow,* 2010; *Wright et al.,* 2013].

Trend extrapolation is a quantitative forecasting tool. Extrapolation is based on historical data. Diverse variables are utilized. Examples include GDP per capita, life expectancy, and energy demand. Trend extrapolation is often applied to technology diffusion. Rogers' [*Rogers,* 2002] work on diffusion of innovation theory assumes

[2] https://www.rand.org/topics/delphi-method.html, accessed 20.03.2021.

Figure 3. **Number of articles related to: scenarios, forecasting, roadmap or roadmapping, and backcasting**



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that the adopters are classified into five categories (innovators, early adopters, early majority, late majority, and laggards). The cumulative adoption of a new technology over time is described as an S-curve [*Gerstenfeld,* 1971; *Meade, Islam,* 2006; *Rogers,* 2002].

Forecasting technology diffusion is dominated by the Bass model [*Bass,* 1969]. Bass assumes that adopters are influenced by two factors: (1) a desire to innovate and (2) imitation of others. The model estimates the fraction of adopters in a given year. This model is frequently modified, refined, and/or extended (e.g., [*Fan et al.*, 2017; *Seol et al.*, 2012]).

Scenarios

A scenario is *a "hypothetical sequence of events leading to a possible future"* [*Kahn, Wiener,* 1967]. Scenarios have been used to support decision making under uncertainty since the 1950s. Royal Dutch Shell utilized scenario analysis to better manage the first oil crisis (1970s). Since then, scenario planning is a popular corporate strategic decision-making tool [*Wack,*1985]. A number of different approaches are taken to consider the role of scenarios. Examples include (1) the scenario as a story with plausible cause and effect links that connect a future condition with the present [*Glenn*, 2009a] and (2) scenarios that are not about predicting the future but rather perceive the futures in the present [*Schwartz,* 1991]. Most scholars agree that scenarios are not predictions, but descriptors of possible futures that allow for a better understanding of the influence of uncertainties [*Kishita et al.*, 2016, *Spaniol, Rowland,* 2019]. The most essential characteristic of scenarios is to provide possible *alternative* futures in a *narrative* format, helping stakeholders share a common understanding of and think about the future [*Spaniol, Rowland,* 2019; *van Notten et al.*, 2003].

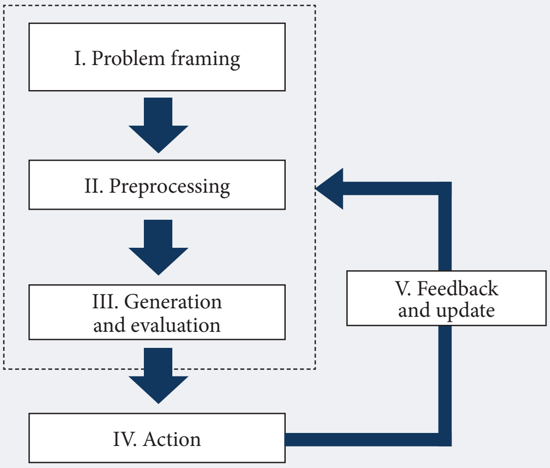
The scenario literature [*Amer et al.*, 2013; *Bishop et al.*, 2007; *Kishita et al.*, 2016] offers a wide variety of methods and techniques. This has been described as a "methodological chaos" [*Bradfield et al.,* 2005; *Martelli,* 2001]. The most prevalent method is to use a 2x2 matrix (i.e., four scenarios) considering the two most critical uncertainties from the external factors [*Ogilvy, Schwartz,* 1998]. One typical way of classification is forecasting or backcasting scenarios, these differ in terms of the vantage point [*Börjeson et al.*, 2006; *van Notten et al.*, 2003]. Forecasting scenarios describe possible futures that might unfold with the present as the starting point. Backcasting, however, describes desirable/undesirable future endpoints (visions) first, after which the paths from the future are drawn back to the present [*Börjeson et al.*, 2006; *Quist, Vergragt,* 2006]. In both cases, a number of scenario development processes have been proposed [*Kishita et al.,* 2016].

Roadmapping

Roadmapping is defined as a structured, temporal, and often graphical way of representing and exploring the dynamic linkages between technological resources, organizational objectives, and the changing environment [*Phaal et al.*, 2004]. Since its introduction by Motorola in the 1970s, technology roadmapping is widely used to support strategy planning and product development at organizations [*Willyard, McClees,* 1987]. It is also applied in sectoral and STI policy contexts [*Carayannis et al.*, 2016; *Yasunaga et al.*, 2009]. Technology roadmaps show the time dimension, often using multiple layers to represent the relationships between markets, goods, services, and technologies [*Phaal et al.*, 2004]. As roadmaps can take a variety of formats, they are designed to be suitable for specific purposes and contexts [*Phaal et al.*, 2010].

A number of roadmap development methods are in use [*de Alcantara, Martens,* 2019; *Park et al.*, 2020; *Vatananan, Gerdsri,* 2012]. Roadmapping is usually combined with workshops to promote communication, sharing,

Figure 4. **A generalized futures and foresight process**



Source: compiled by the author basing on [*Popper*, 2008b; *Voros*, 2003].

and generating knowledge amongst stakeholders. For example, the T-Plan process supports product planning using a standard option to fast-track the roadmap implementation process at an organization [*Phaal et al.*, 2003]. By extending the T-Plan process, value-driven technology roadmaps can integrate decision-making and marketing [*Fenwick et al.*, 2009]. For example, Daim and Oliver [*Daim, Oliver*, 2008] present a framework for implementing technology roadmaps in the energy sector.

An emerging area is combining roadmaps with data-driven approaches to consider the dynamics of the competitive environment [*Geum et al.*, 2015; *Pora et al.*, 2020]. Some scholars have proposed integrating roadmapping and scenarios to assess the influence of future uncertainties [*Hussain et al.*, 2017; *Lee, Geum*, 2017; *Saritas, Aylen*, 2010; *Siebelink et al.*, 2016]. Integration increases the roadmap's robustness, thereby, providing better support for decision-making.

Advancing Methodological Development in Futures and Foresight

Futures and foresight are interdisciplinary and transdisciplinary activities involving diverse knowledge bases to address complex problems at organizations or in society [*Kishita et al.*, 2021]. Figure 4 illustrates a generalized futures and foresight process that generates, evaluates, and manages knowledge about the future through the involvement of researchers, practitioners, and stakeholders. Each process step is briefly described in Table 1. A participatory approach (using workshops involving experts and stakeholders) is often used to run the process.

While there are many methods to generate knowledge about the future, there are many questions related to methodology development that need further consideration:

- To what extent can digital technologies, artificial intelligence (AI), and other data-driven approaches support and enhance futures and foresight activities?
- What are the prerequisites for maximizing the benefits of utilizing the outputs of futures and foresight activities in order to solve the problem being addressed?
- Which part of the futures and foresight process can be more diversified and personalized to reflect needs in society and/or on the market? Exactly how will this be achieved?
- To what extent can the outputs of futures and foresight activities be evaluated before implementation (i.e., prior to Step IV)?
- How can decision-making be supported in a more agile and appropriate manner? How is this impacted by market competitiveness?
- As sustainability is increasingly important, what sort of methods and techniques help to generate useful knowledge to cover a longer time horizon (e.g., 2050 or 2060)?
- How should futures and foresight methods be adjusted or adapted in the future due to the impacts of

Table 1. **Stages of futures and foresight process**

Stage	Description
I. Problem framing	Defining the objective to be addressed, while specifying the theme/domain to be investigated, the spatial and temporal boundary of concern, and who is to be involved.
II. Preprocessing	Preparing for knowledge generation by selecting methods to be used (e.g., forecasting, scenarios, and roadmapping), collecting data from external sources (e.g., literature, websites, and interviews), determining the detailed process, and recruiting workshop participants.
III. Generation and evaluation	Generating knowledge about the future, delineating possible futures based on collected data and generated knowledge, and evaluating these futures.
IV. Action	Adopting the outputs of Step III to support decision-making, strategy planning, and policymaking.
V. Feedback and update	Feedback to one or more of Steps I-III based on Step IV results. Updating or improving based on the additional insights.

Source: compiled by the author.

COVID-19 (given that the pandemic has caused a drastic change in people's workstyles relating to the use of virtual environments)?

Recent developments in digital technologies and Artificial Intelligence (AI) allow a huge amount of relevant data and insight to be accessed efficiently [*Gordon et al.,* 2020]. Some scholars are using these technologies for futures and foresight activities. Examples include text mining [*Kayser, Blind,* 2017; *Ozcan et al.,* 2021], web mining [*Kayser, Shala,* 2020, *Kehl et al.,* 2020], machine learning [*Zhou et al.,* 2020], and graph theory [*Kishita et al.,* 2020]. Gordon et al. [*Gordon et al.,* 2020] note *the blending of AI-generated and human-generated insights and their impact on decision-making is an interesting question for case studies in organizations*. Also worth noting is that stakeholder engagement has recently been considered in the futures and foresight context using an action research approach [*Gattringer, Wiener,* 2020; *Lehoux et al.,* 2020].

Filling the Gap between Methodological Challenges and the Current Status

The five papers in this special issue contribute to methodological development in the field, tackling a number of the questions raised above.

Daim et al. in the paper 'Forecasting Technology Trends through the Gap Between Science and Technology: The ase of Software as an E-Commerce Service' focus on technology forecasting to identify technology trends. This offers important help to companies to define potential markets for innovative products and services. They apply text mining techniques with expert judgment to a technology forecasting methodology. Drawing on scientific papers and patent information as data sources, text mining reveals trends in Software as a Service (SaaS) technology. Through gap analysis (scientific papers vs. patents), five technological trends are identified. The proposed method is widely applicable to the needs of stakeholders in industry, government, and academia.

Velasco et al. in the paper 'Repositioning People in Creative Futures: A Method to Create Sound Advice with Exploratory Scenarios' investigate how advice and recommendations are generated from scenario development. They analyze the influence of different future scenarios on the process of making recommendations. This is achieved by undertaking a deep analysis of scenario workshops on the future of the European Research Area (ERA). They find that it is valuable to reposition participants in transformative scenarios where in doing so participants situate their views in a hypothetical future context to make decisions contributing to the fluency and creativity of ideas.

Lee et al. in the paper 'Roadmapping in the Era of Uncertainty: How to Integrate Data-Driven Methods with Expert Insights' utilize 10 years of technology planning related to the noise, vibration, and harshness (NVH) of automobiles to illustrate an integrated data-driven and expert-based approach to roadmapping to better support decision-making related to STI. They develop a workshop-based roadmapping process consisting of three stages, i.e., ideation, selection, and planning. Data analysis during the workshop process supports idea generation and evaluation. The data inputs (patents and scientific publications) help experts generate, identify, and evaluate more ideas based on trend analysis both within and external to the sector.

Murata et al. in the paper 'Knowledge Co-Creation Roadmapping for Future Industrial Visions: a Case Study of Smart Infrastructure' integrate an organizational knowledge creation process model. More specifically, they introduce a Socialization-Externalization-Combination-Internalization (SECI) model (Nonaka 1990) into roadmapping to promote knowledge sharing and generation among multiple stakeholders. New knowledge is generated through the interaction of tacit and formal knowledge as participants move through the four steps of: socialization, externalization, combination, and internalization. By iterating through the four steps, Murata et al. demonstrate the value of the method as a communication tool in developing a roadmap for smart social infrastructure enabling collective knowledge creation.

O'Sullivan et al. in the paper 'Agile Roadmapping: an Adaptive Approach to Technology Foresight' focus on the challenge of the limited guidance in ensuring roadmap outputs that are strategically relevant, appropriately detailed, and credible. Emphasis is placed upon the structured and graphical nature of roadmapping. The key patterns of data distribution on the roadmapping canvas identify potential sources of foresight evidence failure. Hence, the roadmapping canvas provides a diagnostic function to examine the sufficiency, efficacy, and credibility of strategic foresight evidence. The implications for roadmapping practice are five principles for adaptive roadmapping to be added to methodological guidelines.

Conclusions

A review of futures and foresight methods focusing on forecasting, scenarios, and roadmapping has been provided. Critical questions for the future development of methodology in futures and foresight have been offered. A series of important papers furthering methodological developments in this field have been introduced. Daim et al. and Lee et al. show how data-driven approaches can support data collection and knowledge generation. Such methods provide the potential to augment people's creativity in generating new knowledge about the future. Velasco et al. and O'Sullivan et al. clarify the critical relationship between knowledge generation and the outputs of futures and foresight activities. Velasco et al. and O'Sullivan et al. provide useful guidance to improve how better outputs are obtained from futures studies. Murata et al. promote stakeholder engagement enabling diversified knowledge and identifies what needs to be better exploited. These five contributions address many concerns with the questions of:

- To what can extent digital technologies, artificial intelligence (AI), and other data-driven approaches support and enhance futures and foresight activities?
- What are the prerequisites for maximizing the benefits of utilizing the outputs of futures and foresight activities in order to solve the problem being addressed?
- Which part of the futures and foresight process can more diversified and personalized to reflect needs in society and/or on the market? Exactly how will this be achieved?

Nevertheless, there is still a need for the consideration of the following important questions:

- To what extent can the outputs of futures and foresight activities be evaluated before implementation (i.e., prior to Step IV)?
- How can decision-making be supported in a more agile and appropriate manner? How is this impacted by market competitiveness?
- As sustainability is increasingly important, what sort of methods and techniques help to generate useful knowledge to cover a longer time horizon (e.g., 2050 or 2060)?
- How should futures and foresight methods be adjusted or adapted in the future due to the impacts of Covid-19 (given that the pandemic has caused a drastic change in people's workstyles relating to the use of virtual environments)?

Finally, as futures and foresight are fundamentally transdisciplinary in terms of not only the topics considered, but both the inputs and outputs, there is a strong need to involve researchers and practitioners from diverse disciplines. Once such an approach is fully understood, futures and foresight methodologies can be utilized to their full potential for the consideration of more micro issues (organizational concerns), broader economics (sectoral or geographic concerns), and grand challenges (global concerns).

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Forecasting Technology Trends through the Gap Between Science and Technology: The ase of Software as an E-Commerce Service

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Abstract

Identifying technology trends can be a key success factor for companies to be competitive and take advantage of technological trends before they occur. The companies always work to plan for future products and services. For that, it is important to turn to methods that are used for technology forecasting. These tools help the companies to define potential markets for innovative new products and services. This paper uses text mining techniques along with expert judgment to detect and analyze the near-term technology evolution trends in a Software as a Service (SaaS) case study. The longer-term technology development trend in this case is forecasted by analyzing the gaps between science and technology. This paper contributes to the technology forecasting methodology and will be of interest to those working with SaaS technology. Our findings reveal five trends in the technology: 1) virtual networking, 2) the hybrid cloud, 3) modeling methodologies, 4) mobile applications, and 5) web applications. Among the results achieved, we can summarize the interesting ones as follows: it is possible to say that traditional information systems are now evolving into online information systems. On the other hand, the use of a licensing model based on subscriptions triggers the change in perpetual licensing models. The product range that has evolved toward mobile technologies has put pressure on information storage technologies and has led to the search for new methods especially in the development of database systems.

Keywords: technology trends; technology forecasting; technological trajectory; text mining; e-commerce; software as a service; SaaS; patent citation

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Forecasting the trend of technologies creates potential opportunities for companies in the industry and for governments to engage in international competition. The business world is dynamic. Companies always work to plan for future products and services. For that, it is important to turn to methods that are used for technology forecasting. These tools help the companies define potential markets for innovative new products and services. In recent years, it has been shown in different research and development projects that patents and scientific papers contain considerable amounts of important information about developed technologies [*Kim, Bae,* 2017]. Identifying technological trends and acting upon them can give enterprises and countries a strategic edge which results in more progression in society and an advantage in global competition [*Li et al.,* 2019]. Most critical decision makers are aware of the importance of being ahead of competitors in detecting and taking advantage of technological trends particularly in our current knowledge economies. Therefore, if organizations, either profit or nonprofit, want to gain sustainable competitive advantages, they need to move early in identifying emerging technologies and pursue the continuous process of innovation which will result in their competitiveness and development. So, in following this approach as a strategic issue one should ask how we can identify technological trends ahead of competitors and forecast the next stages of emerging technologies to create more wealth for society. This is not only important for identifying technological trends but also shows the probable pathways for disruptive technologies. In order to answer the question concerning the identification and forecasting of technological pathways, this paper provides a framework and uses SaaS technologies as a case so that we can understand the evolutionary growth of a technology and possible future states.

The aim of this study is to apply text mining and citation analysis of scientific papers and published patents in software as a service or SaaS technology to reveal the technology trends in this industry and apply it as a technology forecasting approach. The method used in this paper can be applied by industry, government, and academia to develop technology investment and development plans.

Literature Review

As the computational capacity and abundance of data and information have been increasing in this era of big data and artificial intelligence, scientific research has access to powerful tools that dig deeper into the fruitful sources of data to understand the future scenarios of scientific and technological trends. Scientific papers and patents are important containers of information about technologies that can be exploited using novel techniques in order to understand emerging patterns of technological trends. Some methods like text mining and patent analysis allow researchers to investigate technological documents and mine for useful information in a systematic way [*Madani, Weber,* 2016]. Therefore, patents and scientific papers have been widely used as a source of data in revealing the technological trends and their consequences [*Ghazinoory et al.,* 2013; *Huang et al.,* 2018; *Kim, Bae,* 2017; *Madani, Weber,* 2016; *Park, Yong,* 2017; *Wang et al.,* 2015; *Yoon et al.,* 2014]. In fact, technological forecasting has been mostly developed by applying qualitative methods which today are often complemented by quantitative approaches. As more powerful computational tools allow, citation analysis, co-word analysis, patent analysis, topic analysis, bibliometric analysis, and text mining have become popular among a diverse range of available methods in technology forecasting. The appearance of the software-as-a-service (SaaS) business model has attracted big observations from both researchers and practitioners [*Ma,* 2007] and the determination of the future potential of Software-as-a-Service for company applications is considered a pivotal input for software companies' strategy growth [*Cusumano,* 2008]. The integration is a necessity in SaaS adoptions since SaaS contains business data and logics [*Elfatatry et al.,* 2002]. For that, forecasting technology helps to assist the SaaS integration life cycle.

Text Mining

Text mining is one of the emerging techniques in analyzing technological trends and forecasting. It can empower researchers to assess and visualize technical information and patterns in scientific papers and patent documents [*Madani, Weber,* 2016]. Basically what text mining does on these technical documents is mining and finding bucketed constructs of words with the highest frequency and importance so as to focus on the deeper meaning that can be captured from this contextual information [*Rezaeian et al.,* 2017]. Analyzing the characteristic features of extracted patterns over time brings a larger picture to the surface in identifying technological trends and pathways. Many scholars have been applying text mining methods to show the relationships among different keywords, citation referrals, and co-occurrence of words to extract and visualize technological trends and their technical associations which can be applied in the technology planning phase [*Boyack et al.,* 2018; *Ghazinoory et al.,* 2013; *Huang et al.,* 2018; *Rezaeian et al.,* 2017; *Yoon et al.,* 2014].

Although fitting text mining models can provide an approximation about the schemas in a technical area, the trend of the detailed content is not easily illustrated. It is difficult to decipher the association between keywords and specific topics. In fact, the temporal patterns of keywords do not necessarily demonstrate the topic of a technological concept [*Chen et al.,* 2017]. Therefore, the extraction of meaning from the results of pure text mining upon only keyword analysis can be very difficult.

Citation Analysis

Citation analysis generally refers to the insights that come from the knowledge relationships between a network or cluster of papers and patents in specific area of knowledge. So, it has been extensively used to reveal the trends surrounding technological innovations [*Garcia-Lillo et al.,* 2016; *Kostantinos,* 2019; *Angelou et al.,* 2019; *García-Lillo et al.,* 2019; *Teufel et al.,* 2009].

Citation analysis reveals the hidden relationships and structural properties in scientific papers and patents that demonstrate the commonalities of knowledge flows that share specific connections. Through applying this approach in digging deeper into the clusters of papers and patents related to the path of technological trends and new developments, valuable evolutionary patterns of technological moves can be identified. Scholars have extensively applied citation analysis to study technology development trends [*Angelou et al.,* 2019; *Boyack et al.,* 2018; *Hasner et al.,* 2019; *Kim et al.,* 2016; *Kose, Sakata,* 2018]. For instance, Boyack et al. did a large-scale analysis of in-text citation that revealed the higher-level scientific relationships between multiple research areas which would be beneficial in structuring research questions. Such an assessment would probably be efficient in identifying technological convergence which emerges from seemingly unrelated areas of science and technology [*Boyack et al.,* 2018].

Scientific papers and technological patents are invaluable sources of technological knowledge which can be exploited and mined using the available computational tools. However, some scholars assume that just concentrating on citation analysis would not be comprehensive [*Madani, Weber,* 2016]. Novel data science techniques, statistical learning methods, and computational tools can highly improve the level of analysis that scholars do using text mining, which delves into the detailed knowledge contained in multiple technological developments and trends. Analyzing the fundamental characteristics of words and their frequency in the documents can potentially show the deeper meaning behind these relationships. But one drawback of such keyword mining in co-word assessment is the concept of meaning which arises from such connections. Text mining methods that solely rely on the counting of words and their frequencies would frequently miss the important part of the concept which can be elucidated by human expertise.

Technology Forecasting

Technology forecasting is a class of systematic methods that demonstrates the expectations of the future direction, rate of change, and the properties of technological pathways. Scholars have widely used a very diverse set of technology forecasting techniques in different technological domains to better understand the evolutionary paths of technological trends [*Coates et al.,* 2001].

For example, one of the seminal and groundbreaking studies is Christensen's concept of disruptive technologies [*Christensen,* 2000]. The main cornerstone in such research is the concept of the S-curve in tracking the technological trends. The S-curve has been a very useful and simple approach in realizing the differences of sustainable and disruptive technologies. Essentially, technology forecasting is not purely quantitative or qualitative in nature so that, for instance, we come up with a specific quantity and try to apply interpolation.

In the literature there are different types of approaches used in technology forecasting. Lee et al recommended a method relying on the Hidden Markov Model in grouping technologies in the IT sector and present evolutionary patterns [*Lee et al.,* 2011]. Bangisu and Nekhili studied emerging technologies based on a technology forecasting technique which is about analyzing papers and patents. They found a strong correlation between the number of papers and patent data [*Bengisu, Nekhili,* 2006].

There are couple of other methods used in technology forecasting which namely are the S-curve, the adoption curve, text analysis, and so on. This wide range of technology forecasting methods applied in different contexts show that this area of knowledge is very broad and scholars have taken advantage of this diverse spectrum.

Methodology

Text mining is one of the most frequently used methods to follow the change in technology based on experimental data. Text mining for technology management is called technology mining [*Porter, Cunningham,* 2004]. In our study, the technology mining method was used together with bibliometric, sciencemetric, and social network analysis techniques. As a dataset, international scientific publications in Web of Science (WOS) and patent data indexed in Derwent Innovation Index are handled together. Based on the data obtained, inferences were made on the use of software as a service in the electronic commerce sector. For this purpose, the term "Software as a Service" and "E-Commerce" and "SaaS" are used in the terms of query. The bibliographic data obtained in order to clear the publications that should not be included in the study were reviewed. Obtaining the clustered topics is only one part of the forecasting framework used in this paper. Following the work done by [*Li et al.,* 2019], we utilized a six-step process to identify the gaps in science and technology and forecast the future trends of the technology.

Step 1. Data Collection. We utilized the Web of Science (WOS) database for the scientific articles and the Derwent Innovation Index (DII) database to collect the patent information. The query was conducted using the keywords "Software as a Service" and "E-Commerce" as well as the abbreviation "SaaS".

Step 2. Preprocessing the data. The articles from the WOS results had to be cleaned extensively since the Zermatt-SaaS zone is a tectonic unit in the Western Alps and appeared frequently in our searches. Once excluded for geological and other non-software results, we further separated the articles into year published for analysis. The patent information was retrieved and cleared in a similar fashion and separated by year.

Step 3. Various social network theories were used in cluster analysis. In this context, it is preferred to apply a minimum spanning tree frequently in clustering concepts. The minimum spanning tree gives the shortest path around all the nodes in a weighted graph (i.e., the cost (weight) of the paths connecting each node) [*Graham et al.,* 1985]. The Pathfinder algorithm is used to differentiate the clusters where the number of connections is much higher depending on the size of the dataset, thus, it is possible to identify structures consisting of more than one minimum spanning tree [*Chen,* 1998]. CiteSpace software was used to create clusters and calculate the basic social network metrics [*Chen et al.,* 2010].

Step 4. Creating the Hierarchical Structure methodology for the technology. The hierarchical structure was developed with the assistance of an expert in SaaS, who inspected the results of the technological clustering of topics and labeled them into three categories based upon their knowledge and experience.

Step 5. Constructing the Evolution Maps methodology for the technology. Technology evolution maps are used to identify dominant technology areas [*Rongying et al.,* 2010]. The technical topic clusters along with the developed hierarchical structure were used to construct technology evolution maps. The differences and gaps in the two evolution maps are then used in step 6 to forecast the technological trend.

Step 6. Forecasting the Technological Trend methodology. The gaps in technical knowledge between the scientific papers and the patents were used to forecast the trend. Comparing the differences in appearance of technical topics and their rate of growth led us to forecast the future trend. See Figure 3.

Case Study

SThis case study focuses on software as a service (SaaS) technology in the papers and patent dataset and text mining was used to help discern trends. SaaS technology is a type of cloud computing service technology model, centrally hosted and licensed software on subscription basis [*Laplante et al.,* 2008]. In 2001, SaaS first appeared in a Strategic Backgrounder article: Software as a Service, by the Software & Information Industry Association [SIIA, 2001] eBusiness Division. SIIA expected a potential change of software applications filed for personal use, collaborative, and enterprise. And, it was beneficial to reduce time, lower cost, and create a scalable product that was also integrable with another SaaS, easy to use, and highly developed [*Chen et al.*, 2011]. SaaS was selected as a case for this study due to its scientific and technological importance and impact. Therefore, forecasting technology trends from the gap between science and technology of SaaS will significantly assist personal users, managers, policymakers, and developers.

Data Collection

On February 20, 2019, the authors used the Web of Science (WOS) as a research paper database and Derwent Innovations Index (DII) for patents. The term "(Software as a service) OR (SaaS) AND (e-commerce)" was used as the request to explore WOS to find 2,784 papers on the topic from secondary sources from the year 2014 until 2018. The term "(Software as a service) OR (SaaS) AND (e-commerce)" was selected as the request to explore DII to find patents in the database, and 869 issued patents were found from the year 2014 until 2018.

Figure 1 shows the scientific papers and patents related to SaaS technology data selected between 2014 and 2018, and it can be seen that the number of scientific papers and patents increased slightly between 2014 and 2017. The blue line shows the growth in scientific papers from 126 to 147 during the period from 2014 to 2015. The highest rate of growth for scientific paper publications during our review period was 147 papers in 2015. The red line shows the growth in scientific patents from 37 to 69 during the period from 2015 to 2017. Interestingly, the number of patents was highest at 86 patents in 2014, the first year of our review.

Topic Clustering

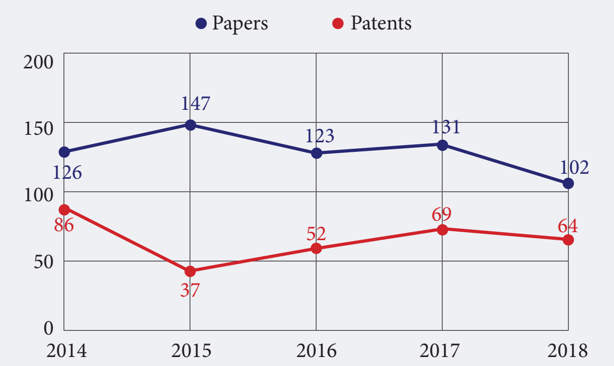
Scientific papers and patents were processed together for every year. They include the keywords that contain "SaaS" and "Software as a service", "Adoption", "Iot", "Qos", and "Game Theory" in the title. The data were saved in plain text format to be processed with Citespace software. We used Pathfinder network scaling to reduce the number of links. With this method we can show the most salient links after the pruning process and subsequent expert validation of the results (expert profiles can be seen in Table 1). After processing this data and reviewing the clustering topics, authors selected up to 50% of the common key terms based on the repetition numbers of the articles that have the selected topic and removed non-relevant topics. Then, the experts focused on e-commerce SaaS technology studies. Experts aided in clustering the results of our topics of research based on their domain knowledge. We obtained topics based on scientific papers and patents for every year along with the expert consultations. The annual extraction results are shown with their represented number of topics in Table 2 and Table 3.

Hierarchical Structure of Technology Generation

A hierarchical structure is a diagram that represents the relationships among technologies based upon each division and subdivision [*Choi et al.*, 2012]. The technological picture represents the connections between product/service components, technologies, or specific technological functions [*Bildosola et al.*, 2017; *Choi et al.*, 2012]. The hierarchical structure of technology generation can be utilized as an in-depth analysis of the technology area selection [*Yoon, Park*, 2005]. This paper has set it out to understand the technological evolution of SaaS technology. It is important to build the hierarchical structure of technology generation to provide the classifications for the topic clustering results. The purpose of doing this for SaaS is to gain an overall methodological understanding of the evolutionary path, determine the gap between scientific papers and patents, and forecast the technological trends for this technology. As mentioned in the methodology section, our cluster topics are treated as objective evidence to make decisions. To find the cluster results from the topic analysis, we combined quantitative and qualitative methods and built the SaaS hierarchical structure. Therefore, our two domain experts engaged in the classification of SaaS topics. First, the experts divided the topics into three categories according to their knowledge and experience and classified each label into a sub-division. The three categories also fully reflect the personal users, managers, policymakers, and developers' directions for the SaaS technology. The following three categories of SaaS technology are considered: "Package software", "Operation system application stack", and "Other; server, storage, network, security, and usability". The "Package software" category addresses the server, data, and code used in SaaS package software technology. The "Operation system application stack" addresses the server, data, and code used in SaaS operation system applications. Finally, the "Other; server, storage, network, security, and usability" is related to the technology keys used in SaaS technology. The result of this information can classify the topic clustering results and generate an evolutionary map to define the technological trends. According to the three selected categories, the experts merged relevant technological topics while each parallel category and layer have mutual functions and characteristics that are related to the technology of SaaS. As shown in Figure 2, the hierarchical structure of the SaaS technology was constructed.

The trend of forecasting technological development is an outcome of defining the path of the technological evolution. The results of topic clustering in the short term are important to understanding the evolutionary path of the software as a service technology. Also, it helps to forecast its development trends for the same period. The map of the technological evolution was constructed based on the scientific papers and another based on the patents. In this case study, our clustering topic results are obtained from scientific papers and patents database from 2014 to 2018 to fully understand the technical topics, which we use to build the evolutionary map of SaaS technology. Firstly, our domain experts categorize the topics in Table 2 and Table 3 that are shown as the hierarchical structure of the technology. The division and sub-division categorizations are shown in Table 4. Then, the evolutionary map of SaaS technology is generated according to the result of clustering the topics from the databases. Lastly, the trend

Figure 1. **Statistical results of scientific papers and patents related to SaaS technology**



Source: compiled by the authors.

Table 1. **Domain Expert Profiles**

No.	Affiliation	Background
1	DePaul University, US	Focused on e-commerce studies for more than 10 years, and working as an e-commerce assistant manager in Saudi Airline Catering
2	Long-Island University, US	Has experience in programming, banking, networking, technical documentation, data report compilation, e-commerce, and e-payment platforms
Source: compiled by the authors.		

of SaaS technology development was examined through the gaps found in the scientific and patent databases based on the created map of technological evolution.

Analysis of the Technology's Evolutionary Path Based on Scientific Papers

Our two domain experts with the help of two senior researchers have selected the technical topics of the scientific papers based on the categorization of clustering results from the period of 2014 to 2018, as shown in Table 5. Table 5 represents the technical topics' appearance year. The number between the brackets represents the number of documents containing the topic. In Table 4, the obtained technical topics in the scientific papers related to SaaS technology in 2014 includes; Cloud Computing, Multi-Tenancy, Reference architecture, Feature Modeling, High Performance Computing, Software Recommendation, Virtual Machine, Radio frequency identification, Digital Campus, Web Application, semantic web, Cloud Service, Storage, Network, and Wireless sensor network. In 2015, many new technical topics appeared for the first time, such as Quality, Multi-Layer Fuzzy Cognitive Maps, Video Mixing, Genetic Algorithms, Hill Climbing, Social Software, Web Service, Service Discovery, Security, Identity Management, and Adoption. In 2016, the technical topics that appeared are Data Isolation, Dynamic Quality Attributes, Learning Automata, Cloud Library Service, and Technology Acceptance Model. In 2017, the following technical topics that appeared are Dynamic Data, Virtual Network Embedding, Hybrid Cloud, Attribute Based Access Control, Privacy Protection and Resource Sharing. In 2018, there are a few new technical topics that appeared. They include SaaS Placement, Modeling Methodologies, Network Effect, and Cloud Tech.

The development of the new technical topics shows that the basic research on SaaS is related to Package Software, the Operation System Application stack and other topics including Server, Storage, Network, and Security. Also, it shows that the basic research development of the technology is slightly increasing.

In Table 5, the technical topics of scientific papers on SaaS between 2014 and 2018 are presented. This table shows that the software package demonstrated a high growth rate in 2014. The operation system application stack showed a high growth percentage in 2015. Security demonstrated high growth in 2017. Overall, the highest rate of scientific paper technical topics appeared in 2015. Forecasting the future development potential of the technology relies on their high growth rate [*Bildosola et al.,* 2017]. Scientific papers that have high growth rates show that those on package software, the operation system application stack, server, network, security, storage, and usability have great development potential. Mobile applications and web applications will be future research focuses of software as a service technology.

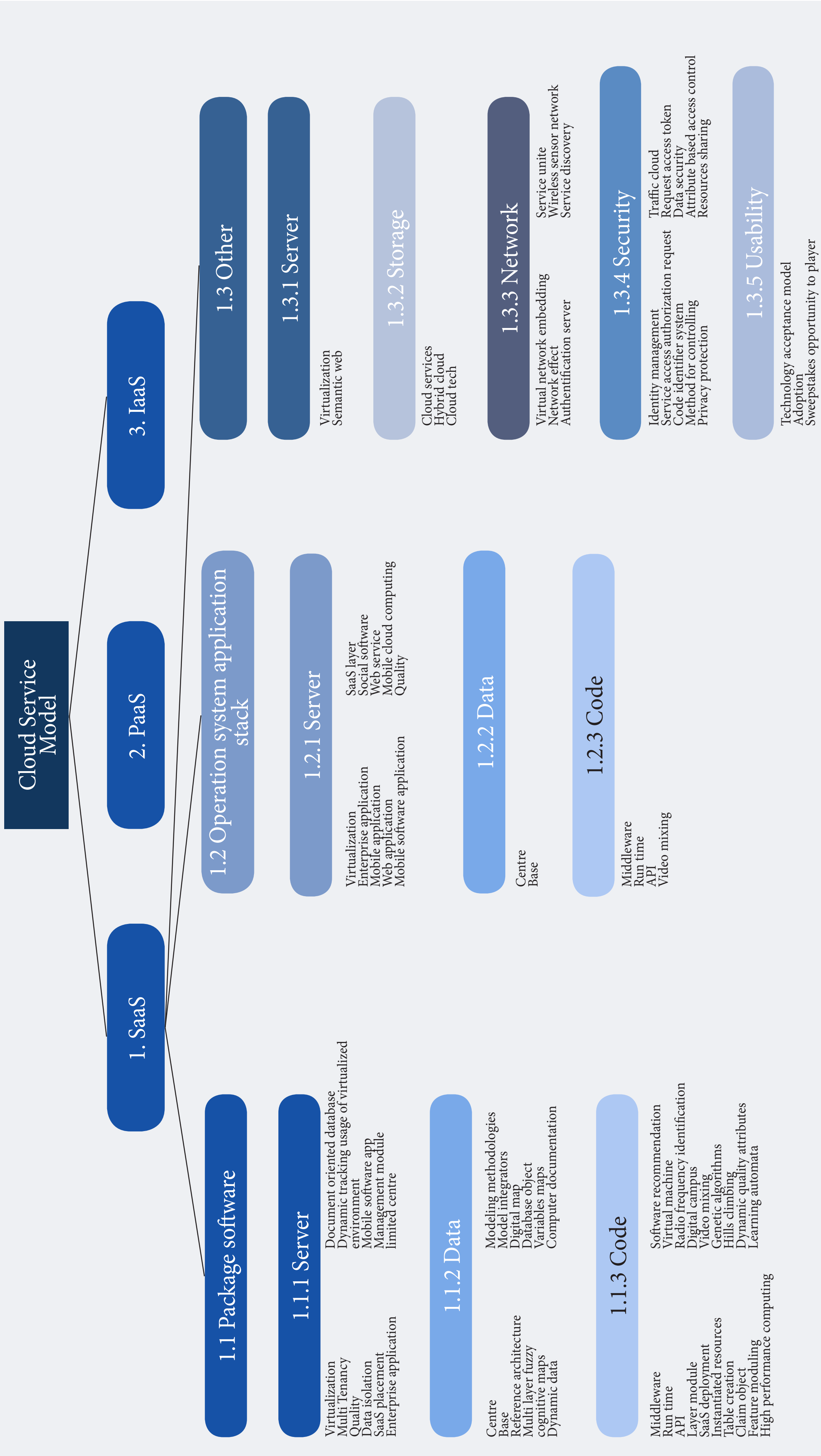
The authors generated the evolutionary map based on the clustering results that have been selected from the scientific database and experts' experience in order to understand the detailed evolutionary path of software as a service technology. Our two domain experts generated the map of the technology's evolution according to its hierarchical structure and the annual technical topics shown in Table 5. We categorized topics into appropriate layers of SaaS and located them on the evolutionary map based on scientific papers in Table 5. As shown in Table 5, the vertical axis represents the Package Software layer, Operation System Application stack layer, and others include the "Server, Storage, Network, Security and Usability" layer of the software as a service technology obtained from the hierarchical structure's first layer. The horizontal axis represents year. By analyzing the variation of elements in each layer over time, we are able to understand the development process of SaaS technology.

It is clear that there has been a change in the debates on information technologies in scientific publications between 2014-2018. It was observed that technologies evolving from traditional information systems to online and mobile information systems and accordingly, information storage methods are in high demand. Information security is also among the other topics that are concentrated upon (Table 5). In the package software layer, there are many technical topics in scientific pa-

Table 2. **Obtained Results of the Topics Extracted from Scientific Papers**

Year of publication	Topic (number of publications)
2014	Multi-tenant SaaS (27); SaaS Security (26); Cloud Computing Technology Application (22); Enterprise Systems (16); SaaS Pricing (11); Engineering Approach (10); Number of Companies (4); Relational Tables (4); Service Request Scheduling (4); Automated Testing (2).
2015	Infrastructure as a Service IaaS Providers (22); SaaS Web Service (22); Multi-tenant SaaS (20); Component Services (17); SaaS Testing (17); Business Processes (13); Mobile Network (11); Security Challenges (11); Big SaaS (9); SaaS ERP (5).
2016	Cloud solutions (34); Design and Development (23); Business Processes (19); Data Storage (18); Factors for Adopting (11); Allocate Resource (6); SLA Violations (5); Sentimental Analysis (3); Retrieving Images (2); Security Testing and Performance Testing (2).
2017	Secure Service (23); Algorithm for SaaS (18); SaaS Companies (18); Multi-tenant Service (15); Software Testing (15); System Performance (15); Applications need to be Tested (14); Services Composition (6); Quality Attributes (4); Education Institution (3).
2018	Service Selection (8); Course (5); Customization Strategies (4); Composite SaaS Placement (3); Image (3); Data Analysis Workflows (2); ERP Software (2); ERP Software (2); Tenant Isolation (2); E-Learning (2); SLA Violations (2).
Source: compiled by the authors.	

Figure 2. **Hierarchical Structure of SaaS Technology Based on Text Mining and Expert Knowledge**



Source: compiled by the authors.

Table 3. **Obtained Results of the Topics Extracted from Patents**

Year of publication	Topic (number of patents)
2014	Cloud Infrastructure System (14); Managed Mobile Application (13); Tenant of Tenants (13); SaaS Usage (11); Cloud Monitoring (10); Information Indicative (10); Module Integrator (6); Particular Device (5); Hardware Layer (2); Table Creation (2)
2015	Mobile Application (8); Application Instance (6); Instantiated Resources (5); Service Account (5); Client Node (3); Group Transaction (2);Map Viewport (2); Patent Database (2); Requested Content (2); Sweepstakes Opportunity to Player (2)
2016	Enterprise Computing Environment (8); Management Module (8); Authorizing Access to a Service (7); Business Resource (6); Method for Integrating (6); Code Identifier System (3); Instructions for Navigating (3); Code Analysis System (2);Dynamically Tracking Usage of Virtualized Environment (2)
2017	Management Module (18); SaaS Virtual (15); Mobile Software Applications (9); Operating State (7); Client Terminal (6); Traffic Cloud (5); Database Object (3); Digital Map (2) Oil Carrier (2); Variable Term (2)
2018	Authentication Server (11); Service Unit (10); SaaS Layer (9); Management Module (8); Computer Documentation (7); Access Token (6); Secure Machine Environment (4); Shared Key (4); Set of Objects (3); Account Number (2)

Source: compiled by the authors.

pers related to SaaS technology such as: Multi-Tenancy, Reference Architecture, Feature Modeling, High Performance Computing, Software Recommendation, Virtual Machine, Radio Frequency Identification, and Digital Campus have appeared with changes over time, which shows that cloud computing gradually changed from 2014 to 2015. The first layer of the SaaS "Software package" includes server, data, and code. The "server of software package" includes multi-tenancy technology which appeared in 2014 and increased by 2017, quality in 2015, and data isolation in 2016. In SaaS "operation systems and application stack" there is server, data, and code. The "server of operation systems and application stack" includes web applications that appeared in both 2014 and 2015, web services in both 2015 and 2018, quality in 2015, mobile cloud computing 2015, and social software in 2015. In the "code of operation systems and application stack", video mixing appeared in 2015. In the "operation systems and application stack" there was a development in the web application technology and web service technology regardless of the gap in the development of scientific papers on the subject between 2016 and 2017. The third division of the first layer of SaaS "Other" includes server, storage, network, and security. In scientific papers on the "SaaS server", the semantic web was the only technical topic to appear in 2014. In scientific papers on "SaaS storage", cloud services appeared in both 2014 and 2016, storage appeared in 2014 and 2017, hybrid cloud in 2017, and cloud tech in 2018. In the scientific paper on "SaaS network", the term network appeared in 2014, wireless sensor network in 2014, service discovery in 2015, virtual network in 2017, and network effect in 2018. In the scientific papers on "SaaS security", security first appeared in between 2015 and 2018, identifying management in 2015, attribute-based access control in 2017, privacy protection in 2017, resource sharing in 2017, and SaaS placement technology in 2016. In the data on software packages, reference architecture appeared in both 2014 and 2015, multi-layer fuzzy cognitive maps in 2015, dynamic data in 2017, and modeling methodologies in 2018. In "code of software package", the virtual machine appeared in 2014, 2015, and 2016, feature modeling in 2014, high performance computing in 2014, software recommendation in 2014,

Table 4. **Classification of the Topic Clustering**

Layer	Element	
Package software	Server	Virtualization, Multi-tenancy, Quality, Data isolation, SaaS placement, Enterprise application, Document-oriented database,
	Data	Dynamic tracking usage of virtualized environment, Mobile software app, Management module, limited center
	Code	Centre, Base, Reference architecture, Multi-layer fuzzy cognitive maps, Dynamic data, Modeling methodologies, Model integrators, Digital map, Database object, Variables maps, Computer documentation
Operation system application stack	Server	Middleware, Run time, API, Layer module, SaaS deployment, Instantiated resources, Table creation, Claim object, Feature molding, High performance computing, Software recommendation, Virtual machine, Radio frequency identification, Digital campus, Video mixing, Generic algorithms, Hills climbing, Dynamic quality attributes, Learning automata
	Data	Centre, Base
	Code	Middleware, Run time, API, Video mixing
Other	Server	Virtualization, Semantic web
	Storage	Cloud services, Hybrid cloud, Cloud tech
	Network	Virtual network embedding, Network effect, Authentication server, Service unite, Wireless sensor network, Service discovery
	Security	Identity management, Service access authorization request, Code identifier system, Method for controlling, Privacy protection, Protection, Traffic cloud, Request access token, Data security, Attribute based access control, Resources sharing
	Usability	Technology acceptance model, Adoption, Sweepstakes opportunity to player

Source: authors.

Table 5. **Technical Topics of Scientific Papers in 2014–2018**

Domain	2014	2015	2016	2017	2018
Cloud Service	Cloud computing (7)	Cloud computing (8); SaaS (1)	Cloud computing (7); SaaS (1)	Cloud computing (5); IaaS (1); SaaS (1)	Cloud computing (5);
Package Software - Server	Multi-Tenancy (3)	Quality (2)	Data Isolation (1); Multi-Tenancy (2)	Multi-Tenancy (4)	SaaS Placement
Package Software – code	Reference Architecture	Reference Architecture; Multi-Layer Fuzzy Cognitive Maps (1)	___	Dynamic Data	Modeling Methodologies
Package Software – data	Feature Modeling (3); High Performance Computing (2); Software Recommendation; Virtual Machine; Radio Frequency Identification, Digital Campus	Video Mixing; Virtual Machine (2); Genetic Algorithms (1); Genetic Algorithms (1); Hill Climbing	Virtual Machine (2); Dynamic Quality Attributes; Learning Automata (1)	___	___
Operation Sys. App. Stack-Server	Web Application (1)	Social Software (1); Web Services (1); Web Application (1); Mobile Cloud Computing; Quality (2)	___	___	Web Based Services
Operation Sys. App. Stack-Code	___	___	___	___	___
Operation Sys. App. Stack-data	___	Video Mixing	___	___	___
Server	Semantic Web	___	___	___	___
Storage	Cloud Service (2); Storage	___	Cloud Library Service (2)	Storage (1); Hybrid Cloud (1)	Cloud Tech (1)
Network	Network (2); Wireless Sensor Network	Service Discovery	___	Virtual Network Embedding (1)	Network Effect
Security	___	Security (4)	Security (1)	Data Security (2); Attribute Based Access Control; Privacy Protection; Resource Sharing	Security (2)
Usability	___	Adoption (2)	Technology Acceptance Model	___	___

Note: numbers in brackets mean the number of articles mentioning the concrete topic.

Source: authors.

radio frequency identification in 2014, digital campus in 2014, video mixing in 2015, genetic algorithms in 2015, hills climbing in 2015, dynamic quality attribute in 2016, and learning automata in 2016. The major technical development of the "SaaS software package" in scientific papers was multi-tenancy technology in servers and virtual machine technology in code. From the second feature of the first paper of SaaS usability, adoption appeared in 2015 and the technology acceptance model in 2016. As a result of finding major technical topics in "server, storage, network, and security", cloud services and security have a higher development level than other technological topics.

Analysis of the Path of the Technological Evolution Based on Patents

We obtained the technical topics from the patents based on the classification of the clustering results from 2014-2018 as shown in Table 6 with the help of our domain experts and the two senior researchers of our expert panel. In Table 6, the technical topics' appearance years are shown. The number between the brackets represents the number of documents containing the topic.

As shown in Table 6, the obtained technical topics in the patents related to software as a service technology includes; Enterprise Application, Module Integrator, Table Creation, Claim Object, Enterprise Application, and Cloud Service in 2014. In 2015, the new technical topics that appeared for the first time are Document Oriented Database, Account Provisioning Component, Digital Map, Instantiated Resources, Mobile Application, and Sweepstakes Opportunity to Player. In 2016, many new technical topics appeared for the first time, including Dynamically Tracking Usage of Virtualized Environment, Web Application, Services Access Authorization Request, Code Identifier System, and a Method for Controlling. In 2017, seven new technical topics appeared for the first time, Variable Term, SaaS Deployment, Traffic Cloud, Layer Module, SaaS Deployment, Mobile Software Application, and Database Object. In 2018, six new technical topics appeared: Authentication Server, Service Unite, Request Access Token, Computer Documentation, Management Module, and Limited Content.

Table 6 shows the applied research related to SaaS technology between 2014 and 2018. In Table 6, the package software section showed a high growth percentage in 2017. The operation system application stack showed a high growth percentage in 2016. Security also demonstrated high growth in 2016. A high growth rate means the high exception of forecasting development for the technological topics package software. The operation system application stack, server, network, security, storage, and usability have great development potential, which also

Table 6. **Technical Topics of Patents in 2014–2018**

Tech. Topic	2014	2015	2016	2017	2018
Cloud Service	—	—	—	—	—
Package Software	Enterprise Application (14)	Document Oriented Database (2); Account Providing Component 120 (2)	Enterprise Application Stores Interface (6); Dynamic Tracking Usage of Virtualized Environment (2)	Mobile Software Application (9)	Management Module (8); Limited Content (8); Enterprise Resource Management Application (7)
	Module Integrator (6)	Digital Map (3)	—	Database Object (3); Digital Map (2); Variable Term (2)	Computer Documentation (7)
	Table Creation (2); Claim Object (7)	Instantiated Resources (5)	—	Layer Module (6); SaaS Deployment (9)	—
Operation System Application Stack	Enterprise Application (14)	Mobile Application (8)	Enterprise Application Store Interface (6); Web Application (7)	Mobile Software Application (9)	SaaS Layer (9)
	—	—	—	Variable Term (2)	—
	—	—	—	SaaS Deployment (9)	—
Other: Server	—	—	—	—	—
Storage	Cloud Service (10)	—	—	—	—
Network	—	—	—	—	Authentication Server (11); Service Unite (10)
Security	—	—	Service Access Authorization Request (5); Code Identifier System (3); Method for controlling (14)	Traffic Cloud	Request Access Token (5)
Usability	—	Sweepstakes Opportunity to Player (2)	—	—	—

Note: numbers in brackets mean the number of patents mentioning the concrete topic.
Source: authors.

means that these technical topics may be the applied research focuses related to SaaS technology in the future.

We generated the evolution map according to the clustering topics that have been selected from the scientific database and experts' experience in order to understand the detailed evolutionary path of SaaS technology. Our two domain experts generated the SaaS evolution map based on its hierarchical structure and the annual technical topics shown in Table 6. We categorized the topics into appropriate layers of SaaS and placed them on the evolutionary map based on scientific patents in Table 6. As shown in Table 6, the vertical axis represents the Package Software layer, Operation System Application stack layer, and others include the Server, Storage, Network and Security, and Usability layer obtained from the hierarchical structure's first layer. The horizontal axis represents the year.

According to Table 6, in package of software, there are many technical topics in the scientific patents related to SaaS technology such as the following. Enterprise Application technology appeared in 2014. In 2015, the Document Oriented Database and Account Provisioning Component appeared. The Enterprise Application Store Interface and Dynamically Tracking Usage of Virtualized Environment appeared in 2016. In 2017, Mobile Software Application appeared in SaaS scientific patents. Management Module, Limited Content, and Enterprise Resource Management Application appeared in 2018. From the feature of the first layer of SaaS "Software package" there is data showing that the Module Integrator appeared in 2014 and the Digital Map appeared in both 2015 and 2017. Also, there is one more technology in SaaS patents: data appeared in 2017 concerning the Database Object. In 2018, Computer Documentation appeared as a technology in the software package in patents of SaaS. Finally, the software package also includes Table Creation and Claim Object, which appeared in 2014 and Instantiated Resources in 2015. Layer Module and SaaS Deployment appeared as a technology in the code of the software package in 2017.The second feature of the first layer of SaaS "operation systems and application stack" includes server, data, and code. In server of operation systems and application stack, Enterprise Application appeared in 2014. Mobile Application appeared in patents in both 2015 and 2017. Enterprise Application Store Interface and Web Application appeared in 2016. In 2018, SaaS Layer appeared in patents. In the data of the operation systems and application stack, Variable Term appeared in patents in 2017 as did SaaS Deployment.

The third feature of the first layer of SaaS "Other" includes storage, network, security, and usability. In the SaaS patents, Cloud Service was the only technical topic that appeared in 2014. The Sweepstakes Opportunity to Player topic appeared in 2015, which encourages companies to pay more attention to this area of online games and create competitive software for customers. In scientific papers concerning SaaS storage, Services Access Authorization Request, Code Identifier System, and Method for Controlling appeared in 2016. Traffic Cloud appeared in 2017. In 2018, Authentication Server and Service Unite appeared in patents concerning the network. Also, Request Access Token appeared in patents for SaaS in security.

Analyzing the Gaps between Science and Technology for Forecasting Technology Trends

In Table 7, the dissimilar evolutionary paths of SaaS technology based on scientific papers and patents using text mining are shown. These tables describe the different progression be-

Table 7. **Comparison of Technology Trends Analysis Based on Scientific Papers and Patents**

Topics	Time of topics appearance		Time leg
	in papers	in patents	
Web application	2014	2016	2
Cloud Service	2014	2014	0
Dynamic Data	2016	2016	0
Mobile Application	2015	2015	0
Identifier System	2015	2016	1
Hybrid Cloud	2017	___	___
Virtual Networking	2017	___	___
Modeling Methodologies	2018	___	___

Source: authors.

tween scientific papers and patents. Understanding the connection between technology and science is important for personal users, administrators, policymakers, and entrepreneurs focusing on the changes of technology [*Shibata et al.*, 2010]. They suggested that in the effective technical studies area, topics that appear in papers but not in patents are taken into account as technological opportunities. Technological opportunities allow for determining technological evolution [*Olsson*, 2005]; consequently, recognizing technological opportunities for forecasting technology development trends is critical. As we see in Table 7, the paper provides a comparative analysis of the first appearance of the technical topics in the papers and in patents database. Authors efficiently recognized the technological opportunities in the area of SaaS technology, which is important to understanding the technology's development trends clearly by comparing the time difference between the first appearance of the technical topics in scientific papers and in patents.

As we see in Figure 3, in 2014 clustering technical topics such as cloud services and web application showed up in the scientific papers, however only cloud service appeared in that year's patents. Therefore, after 2014, the web application can be taken into account as a technological opportunity. The web application showed up in 2016 in the patents. The result validated the predicted technological opportunity.

In Table 7 and Figure 3, in 2015, new technical topics like mobile application and identifier system showed up in scientific papers, but only mobile applications appeared in that year's patents. Therefore, after 2015, the identifier system can be considered a technological opportunity. In the patents, the dynamic data, mobile application, and identifier system appeared in 2016, and only dynamic data appeared in scientific papers in the same year. The validation of these results proved the forecasted technological opportunities. Consequently, it is possible to identify technological opportunities according to the time lag between the technical topics that first appeared in patents and papers. In 2017, other technical topics only appeared in papers, such as hybrid cloud and virtual networking. In 2018, new technical topics appeared only in papers such as modeling methodologies. As there are no patents corresponding to the hybrid cloud, virtual networking, and the modeling methodologies before 2018, these three technical topics could become technological opportunities after 2018.

In Table 7 and Figure 3, the high growth rate in 2014 to 2015 in the scientific database concerns web application. However, in patents, the web applications have a high growth rate in 2015-2017. In 2015, the cloud service in papers has a high growth rate, but in patents, the cloud service has a high growth rate only in 2016. In 2015, mobile applications in the scientific database had a higher growth rate while in the patents, the mobile application demonstrated a higher growth rate as a topic in 2015. The virtual machine in the papers and patents had a slow growth rate in 2014, 2015, and 2016. Also, the multitenancy in the papers and patents had a slow growth rate in 2014, 2016, and 2017. Regarding the outcomes, we see that the technical topics with high growth rates first appeared in scientific data. Then, in the patents database, topics followed the same growth trends. For that, we can forecast the changes of technical topics' growth in patents based upon the technological changes in scientific papers.

From these analyses, by evaluating the correlation between the technical topics in the patents and scientific papers, we are able to forecast the changes in technological development. Also, from Table 7 and Figure 3, the authors analyzed the gaps and found the technological development trends.

Also, the high growth rate of technical topics is worth considering when it comes to predicting potential development changes of technology. Knowing the high growth rate of certain technical topics helps to bring the researchers' attention to future studies [*Bildosola et al.,* 2017]. In this study, we have obtained topics from scientific papers and patents. Then, we have compared the growth rates of these technical topics. The aim of these processes is to discover the potential growth trends of these technical topics. The topics in Table 7 are the top topics with high growth rates according to the percentage increase of these topics from 2014 to 2018. There are many new topics that first appeared in 2014 but, again, only those with the highest growth rates were considered. Table 8 shows the annual five technical topics with the highest growth rates. These topics are presented in scientific papers and patents. The number in brackets show the growth rate of the topic with respect to the former year.

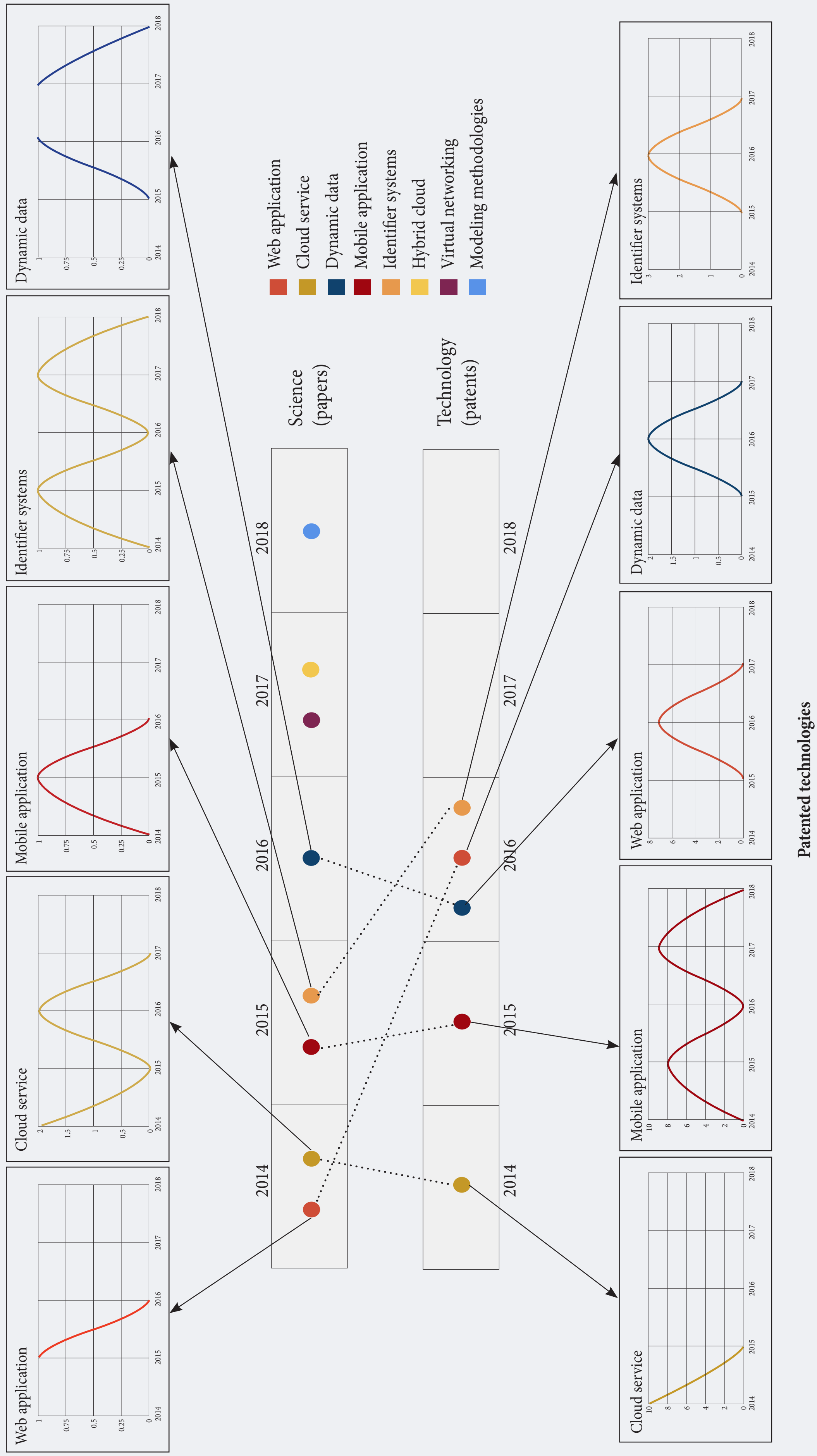
The outcomes of the first appearance of the technical topics in papers and patents and the growth rates of those topics help one have a better understanding of the gaps between science and technology and therefore better forecast technology

Table 8. **Rapidly Growing Topics Covered in Papers and Patents from 2014 to 2018**

Topics	2014	2015	2016	2017
Cloud Service	Cloud Computing (7)	Cloud Computing (8)	Cloud Computing (7)	Cloud computing (5)
Package Software – Server	Multi-Tenancy (3)	___	Multi-Tenancy (2)	___
Package Software	Virtual Machine	Virtual Machine (2)	Virtual Machine (2)	___
Operation System Application Stack	Web Application (1); Mobile Application (8)	Web Application (1)	Web Application (7)	Mobile Software Application (9)

Not: The number in brackets presents the growth rate of the topic with respect to the former year.
Source: authors.

Figure 3. Gaps between Science and Technology Analysis for Forecasting Technology Trends



Source: authors.

trends based on the gaps analysis. By using Table 7, along with Figure 3, we can analyze the gaps between science and technology, and the results are as follows:

(1) Virtual networking first showed up in scientific papers in 2017. While it has not yet shown up in patents, we can forecast that after 2017, virtual networking has high growth potential in patents.

(2) The hybrid cloud first showed up in scientific papers in 2017. While it has not appeared in patents, we can forecast that after 2017, the hybrid cloud will show up in patents with high growth potential.

(3) The modeling methodologies first appeared in scientific papers in 2018. While it has not yet appeared in patents, we can forecast that after 2018, the modeling methodologies will have high growth potential in patents.

(4) The mobile application first showed up in scientific papers in 2014 and presented a higher growth rate in the period of 2015 to 2017. However, the mobile application only appeared in patents in 2016. We can forecast that after 2016 the mobile application will have high growth potential in patents.

(5) The web application first showed up in scientific papers in 2014 and presented a high growth rate in 2014 and in 2016. However, the web application only appeared in patents in 2016. We can forecast that after 2016 the web application will have high growth potential in patents.

We predict that mobile application, web application, hybrid cloud technology, virtual networking, and modeling methodologies will be the future development trends of software as a service technology based on the results of analyzing the gaps between science and technology.

Discussion

This paper adopts a framework developed by [*Li et al.,* 2019] to study technology trends using scientific papers and patents as data resources. This framework is based on identifying a patent and paper dataset and analyzing the gap between the findings, which shows the growth rates in selected technologies. Utilizing text mining to cluster topics shown in scientific papers and expert judgement to identify the technological evolutionary path, we were able to identify trends. Consistent with the original paper, we found that the gap analysis of the first appearance between scientific papers and patents does confirm the development trends. Topics that earlier appeared in scientific papers then appeared several years later in patents suggest a trend. This trend can be used to predict future patents based on topics in the literature.

The evolutionary path of SaaS in e-commerce was constructed in an attempt to better understand emerging and future trends. Our findings reveal five trends in the technology: 1) Virtual networking first appeared in scientific papers in 2017 and we predict that it will appear in patents after 2017 with high growth potential. 2) The hybrid cloud also first appeared in scientific papers in 2017, and again we predict that it will appear in patents after 2017 with high growth potential. 3) Modeling methodologies first appeared in scientific papers in 2018, it has not appeared in patents yet, thus we forecast that after 2018, it will have high growth. 4) Mobile application first appeared in scientific papers in 2014 and showed a higher growth rate in the period between 2015 and 2017. However, it appeared in patents in 2016, we can predict that it will have high growth potential in patents after 2016. 5) In 2014, the web application first showed up in scientific papers and also presented a high growth rate in both 2014 and in 2016. However, it appeared in patents in 2016. We can forecast that after 2016, the web application will have high growth possibility in patents.

Conclusions

According to the results, this paper suggests a framework that employs scientific papers and patents as sources of data and merges text mining with expert knowledge and a judgment method to forecast the technological changes of SaaS technology by recognizing the gaps between science and technology. E-commerce marketing is complex. It needs many skills such as data extraction, transformation, and manipulation. The text mining and expert judgment methods were used for analyzing the technical topics appearing in scientific papers and patents. We applied gaps analysis between science and technology to forecast the technological development changes. SaaS technology was selected as a case study, through which the proposed framework was proven to be effective. The SaaS technology forecasting methodology in this paper focuses on the evolution and future trends of technology research and development.

It is possible to say that traditional information systems are now evolving into online information systems. The main reason for this evolution is the developments in cloud computing technologies. It is possible to attribute the cost advantage of cloud computing technologies to many enterprises without allocating scale. One can say that the three main components of cloud computing technology, service, platform, and infrastructure, consist of software as a service. In this respect, the model drawn in Figure 2 has the potential to be a guide in many sectors, especially in e-commerce. On the other hand, the use of a licensing model based on subscription triggers a change in permanent licensing models. When analyzed by years, the change in technologies is clearly seen. The product range that has evolved toward mobile technologies has put pressure on information storage and storage technologies and has led to a search for new methods especially in the development of database systems.

This paper has limitations that can be addressed in future research. The method was only applied to one area and there were a limited number of observations upon which to build a solid case. In addition, the conclusions were made based on visual observations. The approach can be significantly improved with machine learning techniques enabling the analysis of a much larger dataset and more robust results.

Furthermore, we observed that using scientific papers and patents to predict technological trends also has several limitations. First, important information may be missing because of publishing lag times [Huang et al., 2014]. For future work, additional case studies might look into the time lag of the technical topics' appearances in scientific papers and patents, which could be an opportunity for forecasting technology trends. Second, some science and technology developments are published but not all of them, and some of the records are valuable [*Porter, Detampel,* 1995]. Therefore, a scenario-planning technique combined with text mining may be valuable in further research to forecast the changes of the technology and model the future development of that technology. Bias in the presented approach can also be addressed by working with an expert panel and automating the process with machine learning techniques.

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Repositioning People in Creative Futures: A Method to Create Sound Advice with Exploratory Scenarios

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Abstract

Foresight scenarios are not only useful presentational devices to show that many aspects of the future are open. Scenarios are means for generating advice that helps policymakers initiate actions in the present or near future that will be of long-term significance. Despite the influence that such advice may have on policy decisions, the Foresight literature has paid very little attention to the creation of policy recommendations. Though reports of scenario exercises frequently conclude with lists of recommendations that follow from the study, there is very little explication of the process whereby advice is elicited from the examination of these future scenarios. This paper addresses this gap, examining how the generation of recommendations is related to the development of scenarios within multiple future repositioning workshop settings. It focuses on the fluency and originality of these recommendations, and how this is influenced by repositioning participants in highly transformational scenarios. Repositioning is the process whereby participants are invited to imagine themselves playing roles in hypothetical future contexts, and on that basis to make decisions or devise strategies as if they actually were immersed in these circumstances. The method proposed and the findings of the case study have implications for why and how this future repositioning approach can be incorporated as a 'key feature' in the design of Foresight activities. The aim is also to raise awareness of the need for more exploration of Foresight recommendation methodology.

Keywords: reposition; foresight; advice; recommendation; futures; innovation; scenario; European Research Area (ERA); soundness; fluency; originality; creativity

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Foresight is widely recognized to be a policy instrument that provides structured anticipation through the examination of alternative futures [*Dator, Rodgers,* 1991; *De Jouvenel,* 1967; *Gabiña,* 2005; *Godet,* 1992; *Havas,* 2005; *Kuwahara,* 1996; *Malaska,* 2001; *Miles et al.,* 2008a,b]. In particular, Foresight activities are often seen as having two main contributions to policymaking [*Georghiou et al.,* 2008]. First is Foresight's capacity to deliver policy advice: the activity may be designed to establish priorities or build roadmaps, to examine the robustness of policies across different scenarios, or to appraise the consequences of different courses of action within changing circumstances. A second feature that has also gathered attention is the use of Foresight to facilitate networking and knowledge transfer, to "join up the innovation system" or to align different stakeholders' understanding of emerging issues. Foresight thus not only supports policymaking by providing information drawn from a wide range of knowledge sources but can also strengthen policy implementation by facilitating policy action through learning processes and knowledge sharing across stakeholders [*Da Costa et al.,* 2008; *Eriksson, Weber,* 2008; *Popper et al.,* 2007; *Salo, Cuhls,* 2003]. Foresight activities can be seen as having anticipatory and recommending phases, the former consisting of explicating ongoing changes and alternative futures, the latter concerning the development of policy advice based on such understandings.

The policy dimension of Foresight may contribute to the integration of different policy actions, prioritizing S&T agendas, and even the creation of partnerships between public and private actors [*Miles,* 2008]. Many policy decisions made today are liable to have long-term implications for social, economic, and environmental affairs, and Foresight can help policymakers expand their time horizons beyond the short term. The usefulness of Foresight has been recognized by the European Commission; its systematic mapping of foresight initiatives in Europe and the world highlighted the systematic, participatory, long-term, and pragmatic character of the discipline [European Commission, 2002; *Popper,* 2009].

By questioning conventional assumptions about future prospects, Foresight facilitates a better understanding of plausible paths and 'visions of change' [*Ramos,* 2017]. The hope is that policies can be more precisely and effectively formulated in light of these future visions.[1] The utilization of plausible scenarios also reveals the ethical dimension of Foresight [*Bussey,* 2014], since it invites policy designers to avoid concentrating their efforts solely on the most immediate present problems, and to consider the needs of future generations. Foresight, and the utilization of future scenarios in particular involves taking the future seriously as a 'principle of present action' [*Slaughter,* 1995], since images of the future can shape the actions taken in the present.

Foresight activities typically involve a combination of multiple techniques, some of which are more logical and deductive (e.g. data analytics, computer simulation), some of which involve more imagination and/or group discussion [*Popper,* 2008a, 2008b]. Various methods and rationales for the creation of images of the future and the articulation of alternative scenarios have been discussed in the literature, and several overviews exist [*Carleton et al.,* 2015; *Masini,* 1982; *Medina,* 1999; UK Government, 2017). Foresight activities frequently include participative and interactive workshops as settings in which to develop alternative futures. Such workshops are defined as "temporary socio-spatial crystallisations of expertise, with a particular sort of socio-spatial group dynamics, in which different instruments and tools are deployed in order to endorse knowledge creation" [*Dufva, Ahlqvist,* 2015]. Workshop participants deconstruct present narratives or contexts and create new empowering and plausible ones for themselves [*Inayatullah,* 2004]. By co-developing new narratives and visions, the participants develop a sense of engagement and ownership [*Ramos,* 2017].

It is crucial that Foresight results are found useful and participant stakeholders can feel themselves strengthened and empowered by effective recommendations [*De Smedt,* 2013]. However, the legitimacy of Foresight is sometimes questioned, not least because of the loose connections between the Foresight activity and the actual decision-making process [*Uotila et al.,* 2005]. This is not just a matter of policymakers necessarily having to take into account political machinations and democratic pressures alongside (and sometimes overruling) the recommendations stemming from long-term analyses. Often a long and complex road runs from the formulation of advice to its eventual acceptance and implementation. There is also the issue that these recommendations sometimes appear to emerge from a "black box". How the Foresight process has resulted in proposals for action remains largely obscure. Thus, documenting the way in which recommendations are related to the prior anticipatory phase – including the production of scenarios - should help secure them more legitimacy. Surprisingly, given that the creation of visions is crucial for the recommending phase of Foresight - during which a range of alternative actions or policy recommendations are generated - very few studies have documented the process whereby Foresight projects generate recommendations drawing on these visions.

Why has there been so little study of the recommending phase in the literature? Perhaps it is because decisions to implement recommendations, regardless of the process utilized to produce them, frequently de-

[1] The term "vision" in English can refer to the capacity of sight and to an image of a possible state of affairs - which may have been produced by the capacity of foresight, but may also have connotations of something rather more supernatural, fantastical, or even psychopathological. Unfortunately, English words such as "imaginary" or "image" are also ambiguous terms. We use "vision" here to mean the more serious appraisal of a possible state of (future) affairs.

pend on a variety of unavoidable and uncontrollable external (often political) influences. There is a substantial body of work, deriving from Operational Research and related approaches, on ways in which choices may be made between alternative actions, they may be ranked in terms of priority, and so on. These methods include Multiple Criteria Analysis, Analytic Hierarchy Analysis, Action Roadmapping, among others [UK Government, 2009; *Mardani et al.,* 2015, *Popper et al.,* 2020]. These technical approaches aim at assessing costs and benefits of options in terms of various criteria; and even so political considerations may prevail when choices are actually made. While sophisticated tools may aid selection among various options, the question of how these options are arrived at receives much less attention (for discussion of morphological analysis, see [*Álvarez, Ritchey,* 2015]. Foresight practitioners have frequently paid more attention to the dynamic and creative processes developed during the definition of future scenarios than to the (potentially dynamic and creative) process of elaborating advice.

The lack of explicit methodologies to create sound recommendations during the advice phase of a Foresight activity means that the suggestions that emerge from scenario studies frequently appear to be rather spontaneous and informal. This recommendation stage is often portrayed as simply involving participants proposing options for action and then engaging in some process of selecting among these. The approach to suggesting options may involve basic brainstorming, perhaps with some more structured elicitation of ideas as related to different policy actors and stakeholders. For example, in the "carousel" setting, sets of participants are asked to move around flip-charts representing different actor types; they annotate each chart with suggestions concerning actions and possibly other ideas, such as timetables for actions, indicators of successful implementation, and so on. [*Miles et al.,* 2016]. In a similar vein, simulation gaming can be used to ask participants to assume different roles ("personas") of some particular actors in the scenarios and to discuss what their perspectives, objectives, and actions might be. Participants' creativity is expected to be higher where these are brought into "collision" - when participants have to think of alliances and counterstrategies. Selection between the ideas generated with these processes may involve, for example, an Eisenhower-matrix type mapping of their attractiveness and feasibility.[2] Participants that have worked on different scenarios may have been asked to make proposals based on the issues highlighted by their own scenarios. There may be an effort at "windtunneling", that is, seeing how far particular policies remain valuable across different scenarios [*Ringland,* 2006]. But how are the ideas tied to the scenarios that have been used?

This is not the only topic that remains underexplored in the Foresight literature. There are very few systematic comparisons of different methods – probably because Foresight activities are rarely conducted as scientific experiments, but mainly as inputs to policy or strategy processes (one exception is the comparison of Delphi and cross-impact approaches to the same topic [*Scapolo, Miles,* 2006]). In the present context, how might scenario workshop methodology affect the ideas generated in those scenarios and the advice that is derived from them? The present paper represents a modest attempt to address these questions, by presenting a method for "repositioning" people in several future scenarios, and comparing the advice derived from immersion in those different contexts. It demonstrates that it is possible to examine such processes during the course of a policy-focused foresight activity. The hope is that a better understanding of the factors that affect the construction of policy advice in Foresight activities using scenario analysis can contribute to the development of more creative and effective recommendations emerging from the process, and that this in turn will increase the prospects for their actual implementation and for the long-term vision really being built into policymaking.

Types of Advice

Advice is a broad concept. It can refer to a single recommendation or compilation of such recommendations (what should or should not be done), and it can also involve detailed explanations of what logic underlies such recommendations (why it should or should not be done). There are the following classifications of advice [*Dalal, Bonaccio,* 2010]:

- Advice in favor of a specific alternative
- Advice against one or more alternatives
- Information: neutral advice providing information on alternatives, avoiding prioritizing or favoring any of them
- Decision support: provide support and guidelines on the decision-making process

Advice for a specific alternative has the capacity to summarize the problem into a precise solution, thus enabling faster decision-making processes [*Schrah et al.,* 2006]; but this sort of advice may eventually limit the decision-maker's autonomy [*Caplan, Samter,* 1999; *Goldsmith,* 1994]. In extremely urgent situations, this may be a cost worth bearing, but such a restriction of freedom can lead to reactance on the part of decision-makers or to loss of self-esteem [*Fisher et al.,* 1982]. There may be less of a sense of losing autonomy in relation to other types of advice that give higher levels of freedom to decision-makers, i.e., advice against alter-

[2] This method is described in [*Miles et al.,* 2016], but does not use this terminology; for an example see [*Huang et al.,* 2016].

[3] The full list of the recommendations derived from this process can be found the ERA Open Advice report [*Popper et al.,* 2015a].

natives, information-oriented advice, or decision support advice.

Some experiments suggest that, in general, the type of advice most preferred by decision-makers is information-oriented advice [*Dalal, Bonaccio,* 2010]. However, this also depends on the geo-political implementation context since, as pointed out by [*Keenan, Popper,* 2008], in some regions (e.g., South America), there is a long-standing tendency to avoid openly making recommendations to the government due to the risk of appearing to be critical of current policy. Only when the advisor is seen as a credible expert, decision-makers may prefer prescriptions, recommendations *in favor of* specific alternatives. Interestingly, advice *against* alternatives was not found to be among the decision-makers' preferred types of advice. There are suggestions that information-oriented advice is more useful for newer rather than experienced decision-makers [*Heath,Gonzalez,* 1995]. Advisors should offer a specific type of advice for each contextual circumstance, e.g. on the different foresight scenarios, and try systematically to include sufficient information on the proposed alternatives [*Dalal, Bonaccio,* 2010]. The recommendations analyzed in the case study of this paper are broadly in line with Dalal and Bonaccio's "Information: neutral advice providing information on alternatives" [*Dalal, Bonaccio,* 2010].

Furthermore, advice can play various roles, among which the category of "providing alternatives not considered by the decision maker" is probably the one most relevant to the present study and to Foresight activities in general. Other functions are the provision of emotional support, of arguments to endorse preconceived options, of insights into decision processes, and so on [*Gibbons,* 2003]. A slightly different classification of advice proposed by [*Cross et al.,* 2001] features some categories overlapping with [*Gibbons,* 2003]. Some are functions of many Foresight activities - for instance, supplying sources of further information and proposing ways of reformulating the problem. These authors point out that different types of advice may be complementary, though it would usually be foregrounded.

Stimulating Creative Advice

As compared to basic methods of forecasting, such as trend extrapolation and simulation modeling, Foresight processes are intended to stimulate creative thinking [*Staton,* 2008] and enable collective learning [*Harper, Pace,* 2007]. The participants create a 'shared collage of futures', which is a valuable output of the workshop in its own right and one that supports the generation of actions. The question is raised of how far the generation of creative ideas with Foresight involves not just the imagination of people, but also results from the anticipation methodology employed [*Dufva, Ahlqvist,* 2015]. This is relevant to the case study discussed below.

From a broad perspective, triarchic theory [*Sternberg,*1985] suggests that intelligence is composed of three parts or dimensions: a) a componential dimension related to the human capacity for analyzing problems (in the case of making recommendations in Foresight activities, this analysis often draws on future scenarios), b) an experiential one related to creativity and intuition (i.e. original ideas facilitate the selection of ways to solve problems that are not business-as-usual), and c) a practical dimension related to adaptation to the context (it sounds reasonable to believe that a high number of alternative ideas elicited in Foresight workshops would increase the chances that final recommendations generated with these ideas are compatible with the actual environment and circumstances).

Creativity is not just evident during the anticipation phase (when scenarios are developed) but throughout the whole Foresight process – including the recommendation phase. The generation of recommendations itself involves a practical application of creativity, though it is quite possible that some recommendations are more or less closely modeled on ideas of which participants were already aware. Rietzschel et al. argue that for ideas to be creative, they need to be both original (unusual) and feasible (useful) [*Rietzschel et al.*, 2010]. The fluency of ideas is seen to be a characteristic of creative people and is arguably as relevant in the recommendation phase as in the design of scenarios. In everyday use, "fluency" has connotations of the easy and flowing articulation of messages. Here we follow [*Guilford,* 1950, 1967] in using the term more restrictively simply to refer to the ability to produce numerous ideas. Eliciting a large number of ideas can enrich the Foresight process, since it allows for discussion around more action alternatives. Although policymakers themselves may not welcome a long list of options for action, the generation of numerous alternatives should increase the possibilities for selecting possible solutions to the problems they address.

There is a huge amount of literature exploring the individual and social psychology of creativity [*Sternberg,* 1998, *Glover et al.,* 1989, *Martin, Wilson,* 2018; *Paulus, Nijstad,* 2019; *Dörfler, Stierand,* 2020]. Although general aspects of creativity differ between individuals, there is a consensus in the literature that fluency and originality of ideas are distinct functions of the concept of creativity. These two elements, together with the flexibility and elaboration of ideas are usually used to measure the outcomes of divergent thinking processes [*Guilford,* 1950, 1967; *Torrance,* 1968, 1974; *Amabile,* 1983; *Weisburg,* 1986; *Paulus,* 2000; *Kincaid, Duffus,* 2004].

The case study described below will explore the capacity of future scenarios to increase the fluency and originality of individuals' ideas in Foresight recommendation processes.

Case Study

Description and Rationale

This study draws on a set of workshops focusing on the future of the European Research Area (ERA). The European Commission's Framework Programme

(FP7) funded a Foresight project in 2012 on the future of the ERA by 2030 [*Daimer et al.,* 2015]. The project, named “Forward Visions on the European Research Area” (VERA) was implemented from February 2012 to January 2015. It aimed to “provide relevant strategic intelligence for the future governance and priority-setting of the RTDI (Research, Technology Development and Innovation) system in Europe and for better adapting science, technology and innovation policy to the shifting global environment and upcoming socio-economic challenges.”[4] A key aspect of the project was the special attention paid to the actor’s definition and selection, based on the stakeholder salience model.[5]

VERA established a set of four exploratory scenarios. These were built with a factor-oriented approach. Key factors were identified, alternatives projections developed for each factor, scenarios defined in terms of combinations of these alternatives, and these scenarios were elaborated upon as texts to be discussed later in the project. VERA differs from many other Foresight projects in that the scenario building team (and workshop participants) did not design or organize the recommendation phase of the project. Thus, participants in the recommending phase should not take part with a sense of “ownership” of, or commitment to, any particular scenario. Table 1 presents the resulting scenarios.

While Scenarios 1 and 2 represented incremental changes in the governance of RTDI, the research landscape and socioeconomic context, Scenarios 3 and 4 reflected new socio-technical regimes, associated with transformative structural changes.[6] Whereas decision-makers will often prefer to envisage futures that involve little change from those extrapolated within a “business as usual” scenario, foresight practitioners have long stressed the importance of challenging these cosy assumptions with scenarios that envisage more transformational change [*Dator,* 2009; *Kahane,* 2012]. While these exercises have often helped to provoke substantial change (Kahane [*Kahane,* 2012] in particular discusses the fall of apartheid in South Africa) and while there are ample examples of business-as-usual scenarios leading to failures to anticipate major shocks to the system, there has been little systematic comparative analysis of the effects of employing scenarios of different types in Foresight projects.

This essay is based upon an action research study that accompanied VERA for fifteen months, from January 2013 to March 2014 [*Velasco,* 2017]. So, instead of the Foresight process simply being conducted according to the facilitators’ notions of good practice, an effort was made to document choices and actions in the exercise and to establish what the consequences of specific design decisions were.[7]

VERA is a major European Commission-funded project that applies Foresight to policy matters.[8] VERA developed a communication flow across different ERA representative actors from multiple knowledge domains, regions, and functional levels. The project facilitated a strategic conversation between these actors to identify strategic options and recommendations around ERA with a long-term perspective. It is hoped that the findings could contribute to designing Foresight processes and methodological choices in future activities.

We cannot generalize from our results to say that these are the typical, let alone the only, pattern of outcomes that will characterize scenario-based Foresight activities, of course. Many more studies would be required to reach such a conclusion. We will look at VERA to identify patterns and phenomena that might be intelligible and explicable on the generation of sound advice. While these might not be replicated in other circumstances, the variations in patterns and themes across different future activities is something that can help us build a theory about the Foresight recommending processes. Research might be designed so as to explore this possibility; practice could be designed so as to capitalize upon it.

The analysis focused on the contribution of scenarios and actors to generate policy advice. As noted above, the connection between future scenarios and the generated advice is a black box, a gap in the Foresight literature. The study of VERA allowed for the possibility of opening the black box to start to bridge this gap. The VERA Foresight process is unusual, in being one in which the anticipatory and the recommending phases were transparently connected and documented.

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[4] http://eravisions.eu/, accessed 26.03.2021.

[5] The Mitchell´s stakeholder salience model [*Mitchell et al.,* 1997] offers a political, operational, and dynamic approach to identifying stakeholders, taking into account the actors’ *legitimacy*, *power* of negotiation, and perception of *urgency*. Delimitating the composition of stakeholder representation in collective thinking processes demands a meticulous identification of actors who are relevant to the process, as well as a clear design of the dynamics guiding their participation. Mitchell’s salience model, which was also initially conceived for the business sector, has had interesting applications in policy intelligence [*Haegeman et al.,* 2012].

[6] As highlighted by [*Popper et al.,* 2015b], “*…there is not one clearly preferred scenario across all the focus groups. For each scenario we actually have stakeholder groups that do not find it desirable. Overall, the societal challenge scenario and the scenario with “experts at the wheel” to focus on sustainability are most often seen as desirable. Interesting deviation of that pattern can be seen, as representatives of the academic world (and to some extent by industry) see major disadvantages in a focus on “local solutions” and a shift in knowledge production towards a less science driven paradigm, as well as by societal actors who opposed the top-down definition of societal challenges. However, we clearly see that a VERA scenario dominated by private industry R&I is least desired across all stakeholder groups, even the majority of industry representatives did not find this scenario attractive.*”

[7] As an action research, the key objectives of the project were to observe, explicate, criticize, and transform social practices. Potential objects of such inquiries include individuals, collectives, patterns, procedures, structures, or behaviors. Action research assumes that there are various ways of actively exploring such objects, interacting with people in the process and acknowledging the subjectivity associated to the researcher’s observations [*Ladkin,* 2004]. Action research is a methodology that iteratively poses questions, plans actions, promotes reflection on research inquiries, seeks alternative actions and explanations, and monitors outcomes [*McKernan,* 1996] thus enabling open access to the project process and results.

[8] In Yin’s [*Yin,* 2014] terms, VERA could be considered a ‘critical case’.

Table 1. **VERA's Four Alternative Futures**

VERA Scenarios	Description
1. "Private Knowledge–Global Markets"	Scenario 1 "assumes that today's European Research Area gradually evolves into what one might call a Global Innovation Area, where research is mainly legitimised by its contribution to innovativeness, competitiveness and growth. As a result of limited public funds, growing inequalities between Member States and the jostling for political influence within Europe, private actors, mainly firms, dominate the financing of the research landscape and thus the setting of research priorities."
2. "Societal Challenges–Joint Action"	In Scenario 2, "today's European Research Area has developed its research and innovation capacities incrementally as efficient responses to the Grand Challenges. This means that economic growth and job creation have become challenges themselves, and that issues like climate change or health protection are perceived as Grand Challenges. In Europe as is the case globally, RTDI and education are considered key preconditions for the creation of sound solutions to these Grand Challenges."
3. "Solutions Apart – Local is Beautiful"	Scenario 3 "captures the vision that today's concept of progress is transformed into a human-centred rationale, where e.g. happiness and quality of life are operationalised into new measures of progress. The after-effects of the global economic crisis are felt deep into the 2020s, and especially so in specific European Member States. Rather than driving societies and Member States apart, economic disparities in Europe create a new sense of community in the pursuit of well-being for all, including the RTDI system."
4. "Times of Crises – Experts at the Wheel"	Scenario 4 assumes that "today's economic rationales (jobs and growth) have been transformed into an approach where a sustainable development path is viewed as the main rationale of progress. Human activities are limited by resource availability and the carrying capacities of ecosystems at all levels – ranging from local cultivation of land to the use of global commons such as the atmosphere. The sustainability rationale has therefore been adopted around the globe, but at different speeds and in a variety of ways".

Source: compiled by the authors using [*Teufel et al.,* 2013].

Exploring the Process of Making Recommendations

The objective of the VERA recommending phase was "to underpin an adaptive, efficient, effective and well-resourced European Research Area (ERA) that fosters innovation and creativity and addresses upcoming socio-economic challenges by a) engaging with key stakeholders to explore strategic responses on the critical issues for the ERA evolution, and b) providing sound recommendations on research and innovation (R&I) policies and their governance and coordination across ERA" [*Popper et al.,* 2015 a,b]. This objective is aligned with the VERA overall mission, which assumes that providing strategic intelligence to the governance of ERA requires the gathering of strategic ideas/responses from the participation of R&I key actors, while acknowledging that intelligent solutions to ERA challenges should be necessary, sufficient, and feasible enough to present adequate levels of soundness.

VERA's recommending phase mobilized a wide representation of European R&I stakeholders (73 participants). It involved seven different focus group workshops. Each of these focused on one part of the spectrum of ERA actors: civil society (Vienna), academia (Manchester), industry (Helsinki), research funders (Berlin), experts on ERA (Barcelona), policymakers (Barcelona), and international stakeholders (Brussels). The selected participants had to represent different knowledge domains and have not participated in the previous design workshops for the VERA scenarios.

A 'literal replication´ [*Yin,* 2014] was achieved through the replication of the approach across seven workshops: they shared the same coordinators, methodology, language (English), length, and presentation material, and took place in similar facilities. This increased the capacity to compare the outputs of different workshops on a level playing field.

Each workshop consisted of the following steps[9]:

1. Presentation of the four scenarios to the participants, by means of documents and a short video. Participants were then asked to individually vote on their most and least desired scenarios.
2. The three most desirable scenarios were used to constitute three discussion groups, with three to four stakeholder participants in each.
3. Each group could select a second scenario of their choice, but all groups were encouraged to consider discussing the least desirable scenario so as to make sure that all four alternative futures inspire or inform the recommendation process.
4. Groups undertook a conversation about two specific future scenarios, with a facilitator prompting the group to address opportunities, threats, and related recommendations.

Table 2 and Table 3 presents a description of the VERA workshops' activity. It shows the number of discussion groups and participants that talked about each scenario. We can see that scenario 2 was the one most discussed by participants, 44 persons, in contrast to scenario 3, which was debated by 30 participants. The average number of participants per group was very similar across scenarios.

Participants were thus asked about R&I system opportunities and perceived threats, as seen particularly from the standpoint of their own institutions, in the event of the scenario materializing. We describe this as them being asked to "reposition" themselves in the scenario, while retaining their institutional allegiances and interests as a stakeholder. Repositioning therefore

[9] For more detailed reporting on the actual stakeholders' strategies and desirability of the scenarios see [*Popper et al.,* 2015b; *Velasco,* 2017].

Table 2. **Number of Discussion Groups in the VERA Focus Groups**

Stakeholder groups	Scenario			
	1	2	3	4
Society	1	2	1	2
Academia	2	2	1	1
Industry	1	1	1	3
Funders	1	3	1	1
ERA experts	1	2	2	1
International	1	1	1	1
Policymakers	3	1	1	1
TOTAL	10	12	8	10

Source: compiled by the authors.

refers to the process whereby participants situate their mindsets in a hypothetical future context and adopt decisions or devise strategies as if they were living or immersed in these contextual circumstances.

All the opinions given by the group were collected in a flip chart and discussed (although agreement was reached by simple discussions, in some cases voting was needed) in order to achieve consensus. A high degree of consensus eventually improves the quality and accuracy of the collective advice, as suggested by [*Yaniv,* 2004].

A large volume of insights was elicited from the seven workshops. systematic cleaning and filtering processes were implemented and applied separately for each workshop, so that we could differentiate and understand the position of each type of stakeholder. Every message generated in a focus group workshop was saved in a database and labeled according to the following criteria:

- In which scenarios was the insight generated?
- Which group discussion (and facilitator) generated the insight?
- Was the insight perceived by the group as an opportunity or as a threat?
- Did the opportunity or threat refer to the R&I system as requested, or instead can it be read just as a stakeholder's particular concern?

Table 3. **Number of Participants in the VERA Focus Groups**

Stakeholder groups	Scenario			
	1	2	3	4
Society (9 persons)	3	6	3	6
Academia (12 persons)	8	8	4	4
Industry (10 persons)	4	3	3	10
Funders (11 persons)	4	11	4	3
ERA experts (13 persons)	4	9	9	4
International (6 persons)	3	3	3	3
Policymakers (12 persons)	12	4	4	4
Total participants for each scenario	38	44	30	34
Participants per group	3.80	3.66	3.75	3.40

Source: compiled by the authors.

- Was the message clearly a stakeholder's recommendation for policymakers or, instead can it be just read as a strategic action of that specific actor?

Since the workshop methodology allowed two scenarios to be discussed by different facilitators, it is possible for different discussion groups to arrive at similar insights related to a given scenario. Such repeated insights were merged into one (with this merging process recorded). The merging process tried to maintain the participants' original expressions, while avoiding interpretations to preserve transparency. Quality of advice benefits from the integration of insights generated from multiple and non-correlated advisors [*Soll,* 1999; *Johnson et al.,* 2001]. After this cleaning procedure, the original database was reduced by around 30% and every single message could be tracked to identify its generating discussion and corresponding facilitator.

An overlapping analysis evaluated how many times the same insight was suggested in different scenarios. The coincidence of recommendations across different advising processes should increase decision-makers' confidence in these recommendations [*Budescu et al.,* 2003].

A summary of the future repositioning and insights integration method can be found in Table 4.

This method is recommended in exploratory-scenario-based foresight projects whose number of participants allows the organization at least four discussion groups. In practical terms, the method requires that facilitators be able to record every elicited insight, so that the analyst could afterwards track them and more efficiently undertake the processes of overlapping and insight integration. Identifying recurrent insights across multiple scenarios and discussion members provides the method with a way of eliciting broader and more diverse advice than would be generated by other recommendation-making alternatives.

Analysis of Results

As noted above, there is a lack of evidence concerning the influence that the anticipatory phase of Foresight has on the recommending phase. Future scenarios bring specific elements, contextual circumstances, values, and perspectives into Foresight discussions, and could stimulate participants' mindsets. This analysis of participants' reactions to the VERA scenarios allows us to examine whether scenarios have the capacity to stimulate the generation of insights. We shall here consider only spontaneous insights directly generated by participants during the workshops. In the final writing and argumentation phases of the Foresight process, advice was elaborated on the basis of the recommending phase, but this is not the focus of the present study.

Two aspects of the insights generated in the VERA workshops will be studied: fluency (the number of insights generated per participant in each scenario) and the originality of these insights.

Table 4. **Future Repositioning and Insights Integration Method**

Repositioning	• Present and allocate future scenarios to the discussion groups, making sure that all alternative futures presented inspire or inform the recommendation process • Ask participants about R&I system opportunities and perceived threats, as seen particularly from the standpoint of their own institutions, in the event of the scenario materializing (as if they were repositioned and immersed in that scenario) • Ask participants to formulate possible recommendations to address the opportunities and threats identified in the context of the scenario
Insights/ Integration	• Label (and save) each elicited insight with information (an auxiliary worksheet is recommended) that includes the scenario upon which this particular insight was generated, and the group discussion/facilitator that generated it. • For each scenario, integrate all repeated insights (across different facilitator discussions) into one that faithfully captures the idea. Thus, you will obtain a shorter list of distinct insights per scenario. • Analyze how many times the same insight was suggested in different scenarios. The coincidence of a recommendation across different scenarios and groups increases decision-makers' confidence in that advice. A list of insights could be provided with a score or ranking based on these cross-scenario repetitions
Source: compiled by the authors.	

Fluency Analysis

The generation of multiple ideas from participants in Foresight projects should in principle allow for the production of more practical solutions and recommendations. Table 5 shows the number of insights generated per participant of the different VERA focus groups for each scenario. While the data does not permit tests of statistical significance, some of these differences are quite striking – notably the differences between least and most stimulating in the society, academic, and policymaker groups.

The table shows that, in terms of insights produced per participant, Scenario 4 was the most stimulating context (see mark ++) for four actors (society, academia, experts on ERA-relevant initiatives, and international stakeholders). Scenario 3 was the most stimulating for two actors (industry and policymakers). Only research funders found Scenario 1 the most stimulating. Scenario 2 did not emerge as the most stimulating for any set of stakeholders.

Considering which scenarios prompted less fluency, Table 5 also shows that Scenario 3 was never the least stimulating scenario for any set of stakeholders (see mark --). Scenario 4 was the least stimulating future scenario for one group (research funders); Scenario 2 the least stimulating for two (academia and policymakers); and Scenario 1 was the least stimulating for four (society, industry, ERA experts, and international stakeholders).

Figure 1 represents the stimulation capacities of every scenario across the seven stakeholders, demonstrating that in the VERA process, Scenarios 4 and 3 had a higher capacity of insight stimulation than Scenarios 1 and 2, whose rate is similar.

Table 6 also adds some observations concerning the stimulation capacity of scenarios, presenting the data in terms of the ranking of scenarios. As well as presenting the number of times that each scenario emerged as the most, and as the least, stimulating, we present a score of each scenario in terms of "Ranking Points" (where least stimulating is ranked 1, most stimulating 4). Scenarios 1 and 2 were more stimulating than Scenarios 3 and 4 only once, while scenarios 3 and 4 were more stimulating than Scenarios 1 and 2 on six occasions. Scenarios 3 and 4 were found least stimulating only once (42 in relation to 28 total points).

This analysis invites reflection on the characteristics differentiating Scenarios 1 and 2 from Scenarios 3 and 4. As described above, the VERA scenarios involved two different types of transitions of the European research landscape. While Scenarios 1 and 2 represented an incremental evolution of RTDI governance, Scenarios 3 and 4 were the consequence of deep structural changes in the European research system.

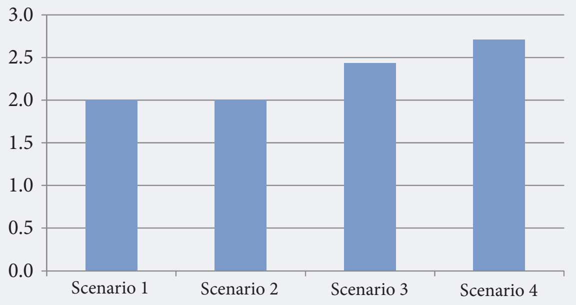
It was the transformational scenarios 3 and 4 that appear to have stimulated the generation of ideas in the focus groups most effectively. Scenario 4, which is a highly transformational and creative scenario, was the most stimulating on four occasions, while Scenario 1 - considered in the ERA scenarios report to be the most familiar and 'baseline' scenario - was the least stimulating scenario in four of the focus groups.

So, in the VERA project, those scenarios that represented higher levels of transformation had more capacity to inspire the creation of recommendations, at least in terms of fluency. The analysis supports the idea that the level of transformation of future scenarios with respect to the present, i.e., the level of differentiation of scenarios vis-à-vis "today's context", can influence the

Table 5. **VERA Scenarios Stimulation Capacity**

Scenario stimulation capacity rate = insights per participant	**Scenario**			
	1	**2**	**3**	**4**
Society	1.3 (––)	2.8	2.3	3.3 (+)
Academia	0.8	0.6 (––)	1.0	2.3 (+)
Industry	2.3 (––)	2.7	3.3 (+)	2.4
Funders	2.8 (+)	1.82	1.75	1.33 (––)
ERA experts	2.25 (––)	2.7	2.33	3.8 (+)
International	1.3 (––)	2.0	2.0	2.7 (+)
Policymakers	2.7	2.3 (––)	4.5 (+)	3.0
Insights generated in each scenario	75	89	73	92
Total across seven groups	1.97	2.02	2.43	2.70
Source: compiled by the authors.				

Figure 1. **VERA Scenario Stimulation Rate**



Source: compiled by the authors.

number of insights generated by the people stimulated with these scenarios.

Originality Analysis

Expert advice – including that from Foresight activities - often reproduces or only marginally extends conventional or commonly debated policy ideas. Creativity is therefore an important element to promote in Foresight projects, not least because systemic issues typically addressed in Foresight require open thinking, holistic approaches, and novel perspectives.

As previously stated, originality is the capacity of proposing more innovative and different ideas than other individuals. It could be argued that personal skills have more influence on the generation of original ideas than the characteristics of the scenarios. The VERA foresight project allows us to explore multiple debates, which should allow us to examine influences that go beyond those associated with the presence of a few highly creative people.

While creativity is often measured on the basis of subjective judgements, we can use a more quantitative approach. This indicator consists of observing, unambiguously, how many "unique" ideas are introduced in each focus group. "Unique" ideas are those which are only introduced by a single type of actor, while not being proposed in another scenario or by a different stakeholder. A comprehensive analysis of data elicited from the focus groups produced a set of these original ('unique' and non-repeated) insights, as reported in Table 7.

Table 6. **Scenario Stimulation Capacity**

Scenario	Number of times		Ranking points	Total
	most stimulating	least stimulating		
1 (realistic)	1	4	12	28
2 (realistic)	0	2	16	
3 (transformational)	2	0	20	42
4 (transformational)	4	1	22	

Source: compiled by the authors.

The table indicates that Scenarios 3 and 4 stimulated the originality of insights (original ideas per participant) to a greater extent than Scenarios 1 and 2. Scenario 2 seems to be least effective and scenario 4 was the most liable to promote the most unique insights per participant.

If we analyze scenarios in pairs, scenario 3 and 4 inspired the highest originality in five of the stakeholder groups, whereas scenario 1 and 2 were most inspiring on two occasions. As in the previously described analysis of scenarios' stimulation capacity, the results suggest that transformational scenarios are useful to favor and stimulate the elicitation of more original ideas.

There are two distinct, but related, interpretations of these results and they may well both apply. First is that when participants are immersed in more radical, unknown, and unfamiliar contexts, they need to look more actively for non-conventional solutions, due to facing new and different problems. Second is that being presented with different and original elements as compared to today's reality, the participants are themselves inspired to think more creatively. In either case, the development of creative thinking in Foresight processes could be stimulated by confrontation with scenarios that differ substantially from those associated with familiar trends. It remains to be seen whether there is an "optimal" level of transformation – so that too much major transformation, too much novelty, is counterproductive.

In summary, the results suggest that repositioning advisors in highly innovative or disruptive scenarios more effectively stimulates the fluency of ideas and the capacity to propose creative solutions, than does repositioning them in conservative or incremental scenarios. The recommendation phase of Foresight processes is comprehensively explained by the "3R" methodological frame ("Reposition", "Representation", and "Resolution") that is utilized to generate sound advice with future scenarios [*Velasco,* 2017] (Table 8)

Arguably, such an effect on fluency and originality is given by the 'surprise' or 'shock' effect that radical scenarios may promote in the advisors' mindset, in contrast to the predictable reactions associated with 'business-as-usual' situations. But this does not mean that Foresight workshops should avoid confronting participants with conventional contexts. Though the discussion of less surprising circumstances may well elicit more standard recommendations, reflection on these may be valuable for assessing the implications of programs and endorsing plans that are already more likely to be considered or implemented.

Discussion

Recommended Situations for Applying the Method

This study has focused on the ways in which considering different scenarios can influence the recommendations developed from a Foresight exercise. Many studies simply aggregate and list recommendations derived able 7. **Originality and Stimulation Analysis**

Stakeholder groups	Scenario			
	1	2	3	4
Society	0.00 (––)	1.00	1.33	2.50 (++)
Academia	0.25 (––)	0.38	0.25 (––)	1.50 (++)
Industry	0.75 (––)	1.67 (++)	1.33	1.50
Funders	2.00 (++)	0.55	0.25 (––)	0.33
ERA experts	1.00 (––)	1.56	1.33	2.50 (++)
International	0.67 (––)	1.33	1.67	2.00 (++)
Policymakers	1.67	1.25 (––)	2.75 (++)	1.50
Total across seven groups	1.03	0.98	1.27	1.74

Note: Number of ideas (per participant) generated by a stakeholder group (in the scenario) that have not been mentioned in any other scenario or by another stakeholder.

Source: compiled by the authors.

from considering alternative scenarios, without indicating how frequently a given recommendation is derived across scenarios, which scenarios do and do not give rise to it. This intelligence could be therefore valuable for addressing complex and systemic problems (the method builds robust recommendations emerging simultaneously across multiple scenarios, thus being applicable to a range of future circumstances) as well as being useful in the event of multiple stakeholders having taken part of strategic debates around those scenarios. The method is also particularly appropriate in circumstances where sponsors and users of the work are liable to require more explication of the ways in which recommendations have been formulated\, and where an effort has been made to develop very different scenarios, especially if some of these are transformative ones. In this sense, the study showed that introducing transformative scenarios in the workshops is helpful in situations where a high number of original insights are required to build sound advice upon them.

Bias

The scenario approach does not presume, in general, that one or another scenario is in some way "correct" in the sense of accurately forecasting the future – indeed, no scenario can be accurate in this sense. What practitioners usually do is to capture a range of possible futures that is relevant to users and can inform meaningful action to steer developments in positive directions. To reduce bias, our method deploys a variety of scenarios and uses them to reposition participants in a particular set of perspectives. By encouraging the development of those multiple scenarios and providing a structured selection of stakeholders to think strategically on them in focus groups, the method effectively reduces the sort of bias that results from assuming that "business as usual" can effectively encompass the future or that there is only one plausible trajectory of development.

Implications for Theory

The study largely draws on theories and was more concerned with applying them than testing them. In particular, it demonstrates the utility of Guilford´s approach [*Guilford,* 1950, 1967] to measure the outcomes of divergent thinking processes and suggests that a fertile line of research in the policy sciences, planning and knowledge management fields would be to examine how far (sets of) recommendations characterized in terms of the different features highlighted by this approach are readily assimilable by decision-makers, whether they need specific messaging and packaging approaches to be effectively deployed.

Exploring the effects of repositioning people in transformative scenarios and assessing the capacity of these scenarios to stimulate the generation of ideas may become an incipient and modest contribution to the theory of creativity that deserves further attention. More empirical studies are yet needed to understand the influence of future scenarios in other manifestations of creative individuals such as the (Guilford's) flexibility of ideas and their level of elaboration.

Implications for Practice

The study implicitly endorses the use of multiple scenarios in Foresight research. However, it should be noted that some scenario studies focus on aspirational

able 8. **"3R" Methodological Frame for Sound Advice**

Factor	Description	Effect on Foresight sound advice
Reposition	This factor refers to the process whereby participants situate their mindsets in a hypothetical future context and adopt decisions or devise strategies as if they were living or immersed in these contextual circumstances. Repositioning participants in highly transformed scenarios stimulates their creativity in particular by facilitating the generation of more numerous and original ideas.	Modulate the number and originality of ideas by repositioning participants in innovative future contexts
Representation	This factor relates to the composition of advisory panels and multi-stakeholder workshops in the foresight processes. The presence of different actors and areas of knowledge within these panels has an important influence on the variety and flexibility of themes/perspectives considered by the participants to find solutions in problem-solving situations.	Adapt participants' perspectives with an adequate representation of actors
Resolution	This is associated to the intervention needed to elaborate upon the advice discourse from the initial insights generated by participants 'repositioned' into incremental or transformational scenarios. Such interventions are supported by argumentation, which influences the type of advice generated and the level of elaboration of the final recommendations.	Increase the quality and soundness of advice with argumentation rules

Source: compiled by the authors basing on [*Velasco*, 2017].

scenarios (these may or may not be thoroughly transformational), while other methods, such as roadmapping, typically deploy just a single scenario. On the practical utilization of scenarios we would suggest that when resources permit, (a) these approaches will be enriched by the preceding exploration and repositioning in multiple scenarios (sometimes an aspirational scenario may be composed from a selection of these) and (b) the full range of recommendations stemming from multiple scenario analysis will enrich those being thrown up in the course of roadmapping and similar efforts. To work on these scenarios, we encourage Foresight practitioners to get a balanced representation of stakeholders, whose coincident insights across focus groups and plausible futures will facilitate the elaboration of more robust advice.

As with all scenario work, face-to-face workshops such as those described in our case study require time and careful preparation, ideally with detailed "scripts" for facilitators. In particular, our method implies that the details of scenarios are clearly conveyed, as they describe contexts in which participants are asked to be repositioned. In this respect, the capacity for adaptation, flexibility, and critical thinking are requested for participants to get the most out of repositioning them in those future contexts.

While it is undoubtedly important for participants to feel comfortable with the scenarios they are using, especially where it comes to working with a vision of the future they can believe as being plausible, there is however a danger of proposing not sufficiently transformed scenarios, so that they find them close to the "most likely" situations, and thus losing the effect on boosting creativity that the method pursues.

Conclusions: Lessons from the Case Study and Implications for Further Research and Practice

Foresight is used to support decision-making around important and complex issues. Although sometimes just providing background intelligence, foresight activities are also frequently asked to provide concrete sets of recommendations. Beyond serving as good presentational devices to show that many aspects of the future are open, future scenarios are used in Foresight activities to support the development of recommendations that can help decision-makers to initiate actions that affect an extended present.

The examination of the VERA project presented here has tackled a gap in the literature: the absence of empirical analysis of how scenario methodologies can shape the advice generated by Foresight activities. It throws some light on the factors that can promote creative knowledge in Foresight workshops.[10] Specifically, it demonstrates that a method for repositioning people in transformational future scenarios can contribute to the fluency and creativity of ideas – at least, the repositioning did so in this one case study. Since the VERA project systematically replicated a substantial number of workshops, we have grounds to think that these results are likely to be significant for other exploratory scenario-based projects. Indeed, similar results could be probably found using other foresight tools, for example wild card generation activities that do not involve a full scenario analysis. Hopefully, the present study provides stimulus for further research seeking to accumulate evidence on these issues. To be sure, many Foresight activities are conducted under such time pressures, and with such budget limitations, practitioners find it hard to mount a systematic exploration of such themes. But it should be possible to collect indicative data from many scenario workshop studies (this may often be less systematic, but could still be indicative). Furthermore, those involved in Foresight education and training could mount experimental studies using their student or participant groups.

Many topics for further research are thrown up by the present study (and some further analyses of the VERA results are to be the subject of forthcoming papers by the authors). Here are some examples:

- The case study involved one type of scenario methodology, for instance – how similar would the results be for a study applying different scenario tools?[11]
- What if the actors involved in the recommending phase are also those involved in the initial scenario development as is often the case – does the process of creatively constructing scenarios affect the depth of repositioning and the extent to which this leads to creative insights?
- Are the results affected by the topic of the Foresight study – would an examination of particular technologies or social issues engender similar patterns of fluency and originality?
- How do differences in individual creativity and in the prior knowledge/expectation of different stakeholder groups affect outcomes? The results presented in the tables above suggest that (a) the influence of scenarios of different types varies across such groups, who (b) themselves appear to vary in terms of fluency and originality. This paper has been more concerned with the overall pattern of influence of the scenario types; but if there are consistent differences in such influence across different stakeholder groups, this may also need to be understood and taken into account in Foresight design.

This study also has implications for Foresight practitioners. In the Foresight design process, they decide not

[10] Some of these factors, such as the influence of facilitators or the imagination of participants, were partially considered by [*Dufva, Ahlqvist,* 2015].

[11] For example, conclusions from [*Miles et al.,* 2016] contrast this 2*2 approach with "archetypes" and "aspirational" approaches.

just on scenario methodology, but also on the extent of elaboration and 'ornamentation' of scenarios. Although exhaustive scenario descriptions can provide varied themes for debate, they could unintentionally also lead to participants' discussions deviating (for better or worse) from sponsors' specific areas of interest.

In fact, expectations about sponsors are liable to play a major role in the formulation of advice based on the recommending phase. Practitioners might consider what expectations to build into the process. For example, should it be stressed that sponsors may not seek "too much" originality, that they may prefer to play it safe and avoid thinking about transformational scenarios? But such "safety" is highly risky when the long term is involved. Practitioners might instead try to focus more on ways of demonstrating that unpalatable plausible futures do require consideration. If such visions are to be taken seriously, the insights from repositioning may be valuable tools for illustrating things that cannot be ignored.

Again, sponsors may also resist large numbers of recommendations and the Foresight team may need to find ways of prioritizing recommendations that avoid relegating too many ideas to categories of minor interest. One approach that is often helpful is to consider bundling up individual actions into "joined up" programs of activity. This is in any case helpful for building on synergies and avoiding inconsistencies and even contradictions across policy efforts, as highlighted in the literature on "policy mixes" [*Flanagan et al.,* 2011]. Practitioners do not always have to undertake such synthesis as a heroic effort after the workshops have concluded but can – if time permits – engage the participants in relevant discussions.

We speculated above that the effect of repositioning might not be linear across different degrees of scenario transformation and this is another topic for research as well as the anecdotal evidence of practitioners. There could be dampening effects of repositioning people in too radical transformations. For example, total disaster scenarios, or ones that are dependent on extreme wild cards, might lead participants to think not much can be done. This could be a matter of believing that the scenario would mean a paralysis of decision-making – or simply that here and now, decision-makers would be unwilling to listen to any recommendations arising from such a future vision. It remains therefore to be studied whether there is an "optimal" level of scenario transformation and demonstrate that, perhaps, too much major transformation and novelty in scenarios may be counterproductive and bring about a negative effect on the generation of ideas.

Another design-related topic for further study involves the assistance that facilitators could give to help participants to easily reposition their mindsets in the proposed future contexts. Facilitators are liable to vary in ability and such skills as imagination, motivation, agility of thinking, and empathy. But some of these capabilities can be gained or enhanced through appropriate training and guidance as to ways of prompting discussion, defusing arguments, and the like can be generated and applied. It would be useful to have more communication across Foresight practitioners as to ways of promoting and gaining value from the repositioning process. One aspect of repositioning that could certainly benefit from more research is the use of role-playing (the "persona" approach, for example, and simulation gaming more generally) as a way of increasing the immersion of participants in specific scenarios [*Fergnani,* 2019]. It is at least worth researching the idea that debates about actions from participants who are playing different roles, could deepen the analysis of scenarios and lead to even more creative insights (including those involving competition and contest, cooperation, and coevolution).

This paper is intended to contribute to the accumulation of knowledge as to the methodological basis of Foresight activities and to open the black box related to the recommendation phase of such activities. We hope to open a discussion on why and how future repositioning can be incorporated as a variable in the design of foresight activities and future-oriented critical issues analysis.

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Roadmapping in the Era of Uncertainty: How to Integrate Data-Driven Methods with Expert Insights

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Abstract

Roadmapping has long been regarded as a practical tool for supporting decision-making for science and technology innovation and it has received recent attention for its potential use in responses to uncertainty. Indeed, roadmapping enables forward-looking strategy making and thus helps to reduce uncertainty. Accordingly, numerous studies have been conducted to propose new approaches to roadmapping for a wide range of contexts, including the data-driven and expert-based approaches. Although these two main approaches have distinct advantages and disadvantages, few previous studies have focused on how to integrate them into roadmapping to better support decision-making related to science and technology innovation. To address this research gap, this study investigated how to integrate data-driven approaches with expert insights during roadmapping. For this purpose, a workshop-based roadmapping method was combined with data-driven methods to test this approach in the context of technology planning for the automobile industry. An ethnographic approach was used to collect data on when, where, and how data analysis must be conducted to support experts' discussions. The research findings open a discussion regarding how to integrate data-driven methods with expert insights during roadmapping based on the trade-offs between the two types of data, that is, hard data for data-driven methods and soft data from expert insights and suggest possible opportunities for future roadmapping developments.

Keywords: roadmapping; uncertainty; data-driven approach; expert insights; foresight

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Technology and strategic roadmaps have long been regarded as flexible tools that can support strategic and long-range planning by matching long-term goals with short-term actions and specific technology solutions [*Farrukh et al.,* 2003]. Since its first introduction by Motorola in the 1980s, roadmapping has been applied to various contexts, including technology forecasting [*Gerdsri,* 2007], new product development [*Petrick, Echols,* 2004; *Lee et al.,* 2008], service planning [*Cho, Lee,* 2014], and R&D project planning [*Cho et al.,* 2016]. On the one hand, regardless of its context, the forward-looking feature of roadmapping helps organizations manage the fuzzy front-end of innovation and survive in turbulent environments, enabling them to reduce uncertainty by collecting the information required to plan for the future. On the other hand, it must be combined with other methods to be suitable for the context.

Among the approaches proposed for roadmapping, the two main streams are the data-driven and expert-based approaches. The data-driven approach uses hard data such as patents to investigate past trends to predict the future [*Geum et al.,* 2015], whereas the expert-based approach relies heavily on expert insights – that is, soft data produced during roadmapping workshops [*Phaal et al.,* 2004]. The representative research group of the former approach is the Seoul School, whereas that of the latter is the Cambridge School [*Park et al.,* 2020]. These two approaches have distinct advantages and disadvantages. The data-driven approach, although it takes a retrospective perspective, utilizes the insights derived from reliable sources to implement systematic analysis techniques. Given recent advances in data analytics, such as natural language processing, deep learning, and artificial intelligence, as well as expanded data sources for investigating innovation activities, the potential for data to support human decision-making is considerable. However, the expert-based approach facilitates the use of tacit knowledge that is not available in the public domain. Furthermore, based on this knowledge, such an approach enables the setting of goals to achieve a desirable future outcome, supporting normative forecasting and exploratory forecasting.

Accordingly, the two approaches can be complementary, and if they are implemented well together in the roadmapping process, they can support better decision-making related to science and technology innovation. Nevertheless, few previous attempts have been made to address this issue; the few exceptions include the work [*Kostoff, Schaller,* 2001], which mentions a hybrid method that combines a computer-based approach (considered a data-driven approach in this paper, emphasizing the importance of data) and an expert-based approach, and [*Lee et al.,* 2007], which summarizes the data analysis techniques that can be used at each roadmapping stage. Indeed, the role of data in successful roadmapping has been highlighted in previous studies [*Lee et al.,* 2011; *Schimpf, Abele,* 2019]. The quantity and quality of information provided to support roadmapping can affect its results. To address this gap in the research, therefore, this study investigates the integration of data-driven approaches with expert insights during roadmapping. For this purpose, a workshop-based roadmapping method was combined with data-driven methods to test this approach in the context of technology planning for the automobile industry, Hyundai Motor Company. A single case study using an ethnographic approach[1] was adopted to collect data on when, where, and how data analysis must be conducted to support experts' discussions. Thus, data needs during the roadmapping process were presented along with the techniques to visualize the data analysis results. The research findings open a discussion on how to integrate data-driven methods with expert insights during roadmapping based on the trade-offs between the two data types and suggest possible opportunities for the future development of roadmapping.

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 the firm and sector levels" [*Park et al.,* 2020, p. 2]. It helps *organizations better prepare for technological change and offers a tool for corporate foresight [Linton, Walsh,* 2004]. Indeed, organizations that use corporate foresight more often are more likely to be engaged in roadmapping and produce more innovation [*Yoon et al.,* 2019]. Due to these advantages, roadmapping has gained significant attention recently and relevant research has increased notably in number [*Carvalho et al.,* 2013; *Park et al.,* 2020]. The number of roadmapping studies exceeded those on other popular planning tools such as Delphi, scenario planning and modeling/simulation [*Park et al.,* 2020]. They also noted that the growth and prosperity of roadmapping studies have led to several research streams, with two distinguished ones including the focus on the design of roadmapping processes, outputs, and on the development of supportive tools for roadmapping [*Park et al.,* 2020]. These research streams are related to roadmapping approaches that are classified into three categories: expert-based, computer-based, and hybrid approaches [*Kostoff, Schaller,* 2001].

The expert-based approach relies on insights in developing roadmaps and involves holding a series of workshops to identify roadmap elements and their relationships [*Wells et al.,* 2004; *Phaal, Muller,* 2009; *Farrukh et al.,* 2003; *Phaal et al.,* 2007]. Moreover, cross-functional roadmapping teams can be organized to provide suf-

[1] Ethnographic approach suggests non formalized, contextually adaptive gathering and analysis of empirical data.

ficient knowledge for successful roadmapping [*Phaal et al.,* 2003; *Gerdsri et al.,* 2010; *Phaal et al.,* 2004]. The relevant studies mainly focus on the development of roadmapping processes or roadmap canvases and on identifying key success factors for procedure. As a result, numerous roadmapping methods have been proposed for choosing technology alternatives [*Garcia, Bray,* 1997], introducing scenario planning [*Groenveld,* 1997], supporting fast-starting roadmapping [*Phaal et al.,* 2003], and managing emerging technologies [*Gerdsri,* 2007]. In addition to the roadmapping process, previous studies also proposed roadmap canvases, both as roadmapping outputs and as roadmapping guidelines. The most representative format is a time-based multi-layered chart, with the top layer mapping business trends and drivers, the middle layer mapping products/services/functions, and the bottom layer mapping technologies. However, these formats can change according to the purposes behind the roadmapping effort. Geum et al. [*Geum et al.,* 2013] proposed a roadmap canvas specifically for open innovation, titled the dual-technology roadmap. Likewise, the relevant studies have investigated the design and customization of the roadmapping process, the structure of the roadmap canvas, and the key success factors of roadmapping. Although expert-based roadmapping based on expert insights is appropriate for corporative foresight, its success may depend highly upon individuals' capabilities—that is, their ability to innovate, willingness to share information, and prior experiences used to justify their decisions. Therefore, it may not be effective in some cultures in which discussions are not encouraged or in areas of convergence in which expert insights are not sufficient to provide all necessary knowledge for roadmapping.

On the other hand, applying data analysis techniques that require a computer to create roadmaps has increased rapidly, possibly with advances in big-data analytics. Producing roadmaps solely via computer-based analysis, where roadmap elements and their relationships are identified without expert intervention, is called a computer-based approach. On the contrary, roadmapping that involves expert and computer-based analyses constitutes a hybrid approach. Previous studies adopting these approaches have generally proposed novel roadmapping methods (i.e., analysis methods) and tested them in practice. Accordingly, these approaches align with the 'application-and-proposition' research stream. First, computer-based roadmapping commonly employs patent data, which is regarded as one of the most rich and reliable sources of innovation. These roadmaps, sometimes called patent roadmaps, were developed to investigate technology trends [*Jeong, Yoon,* 2015; *Jeong et al.,* 2015], monitor competitors [*Lee et al.,* 2012; *Yu, Zhang,* 2019], or establish R&D strategies [*Suh, Park,* 2009]. Using patent data for roadmapping is advantageous because such data improves the credibility of roadmapping outputs. Nevertheless, patent roadmaps have shortcomings when used for corporate foresight due to its inherent retrospective nature and its limited consideration of corporate-level strategies in developing roadmaps.

Second, a hybrid approach aims to overcome the limitations of computer-based approaches and those of expert-based approaches to increase the results' objectivity while maintaining interactions among experts during roadmapping. Existing studies on hybrid roadmapping concentrated on tools to support decisions before, during, and/or after the process. Indeed, expert-based roadmapping often introduced strategy-making methods such as scenario planning and evaluation such as technology valuation to adopt information obtained from them. Many studies combined roadmapping with other decision-supporting tools emphasizing responses to uncertainty. For example, multiple scenarios and their impact on roadmaps are considered [*Geum et al.,* 2014; *Lee, Geum,* 2017], the robustness of roadmaps is analyzed [*Lee et al.,* 2016], and the impact of changes from external and internal factors on roadmaps is evaluated to determine whether the roadmap needs revision [*Gerdsri et al.,* 2019]. Other studies proposed a set of tools for various other purposes, such as a patent and portfolio analysis for prioritization [*Lee et al.,* 2007] and a design-structure matrix for analyzing relationships among roadmap elements [*Son et al.,* 2018]. These decision-supporting tools should greatly improve roadmapping performance, but few attempts have been made to understand how they are used in a real organizational setting. Our knowledge regarding the data source of hybrid roadmapping's needs, how it embeds into the overall organizational process, and how it evolved amongst rapid change is relatively limited. This study aligns with existing literature on hybrid roadmapping and tries to fill the research gap. Consequently, it highlights issues regarding a methodological aspect of hybrid roadmapping and its application at a large corporate organization [*Park et al.,* 2020; *Amati et al.,* 2020; *Simonse et al.,* 2015]. Furthermore, we focus on the information sources necessary to ensure roadmaps' quality.

Proposed Hybrid Approach

The proposed approach has three stages, as presented in Figure 1. This process is based on Cambridge's S-Plan [*Phaal et al.,* 2007], in that the first two stages correspond to S-Plan's landscaping and the last stage is related to the S-Plan's topic mapping. The first stage focuses on the ideation of innovation opportunities, which may come from short-term market and business needs or long-term changes in the technological and business environment. Thus, data for internal and external environment analyses are necessary. The ideas proposed in the first stage are then evaluated in the second stage. After the ideas are grouped into several topics, these topics are prioritized. Finally, for the topics selected in the second stage, detailed plans for pursuing each of them are established. Given that detailed planning requires a comprehensive review of relevant technologies, data analysis results that represent technology trends and available technology solutions are needed at this stage. Using the workshop-based approach, we listed data sources that can support decision-making at each stage of roadmapping based on practical needs and we aimed to integrate these data-driven methods with expert insights.

Stage 1. Ideation

The first stage of roadmapping aims to identify innovation opportunities. The first roadmapping workshop is organized for this purpose. Workshop participants are encouraged to propose such opportunities by answering certain questions – why, what, and how. Those opportunities may arise from the technology-push and market-pull approaches. Technology push derives from new technologies seeking a useful application, whereas market-pull considers innovation opportunities based on market and business demands. Taking a longer perspective, it is necessary to address emerging changes in technological and business environments to facilitate insights that lead to disruptive innovation. During this discussion, although experts propose new business and technology opportunities based on their insights and data analysis, the provision of further information regarding internal and external environment analyses can promote their discussions. Internal sources of information, including customer complaints and survey results, help experts understand current market needs, as well as system, product, or service failures, to examine the limitations of current business offerings and past projects to identify actions taken to overcome the limitations of strategies at a higher level. However, external sources of information can be used to describe trends in terms of patents, publications, and media based on which emerging technologies and competitor's activities are investigated to identify opportunities.

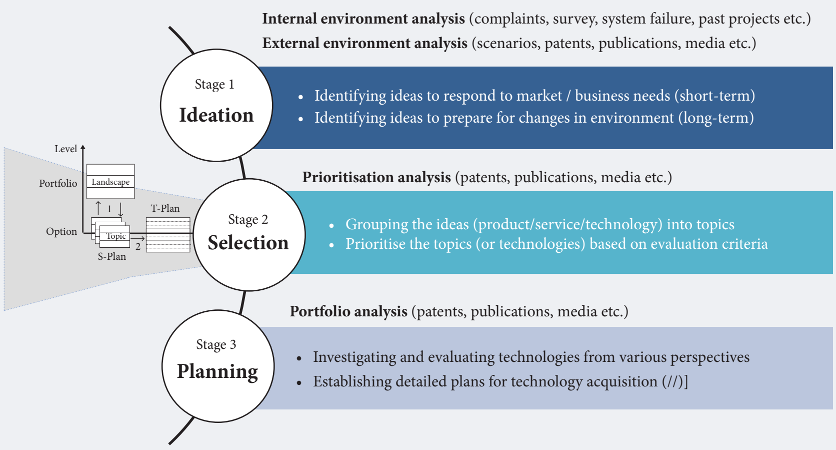
Particularly in cases of high uncertainty, future scenarios can be developed to derive various ideas for each scenario; innovation opportunities are captured for the scenario. Figure 2 describes a workshop template for this stage. If j scenarios are built, j opportunity maps need to be created: some of innovation opportunities may be common across multiple scenarios, while others may be specific to a particular scenario. In the figure, topic (i,j) indicates the i^{th} topic from the j^{th} scenario. In order to help understand scenarios and seize innovation opportunities easily, the use of a value proposition canvas is recommended. The value proposition canvas is a graphical expression of what customers do, need, and suffer from in a specific context and further help design product and service offerings to satisfy the customers [*Osterwalder et al.*, 2014].

Stage 2. Selection

Whereas the first stage is aimed at identifying various ideas, the second stage targets idea selection. As the ideas developed in the first stage may involve similar concepts, they must be grouped into several topics. Likewise, if common ideas are submitted from different scenarios, those ideas must be merged into a single topic. At this stage, many discussions among the workshop participants are held to define the scope and concept of each topic. Once the concept of each topic becomes clear, those topics are prioritized to select the most important ones. Generally, as promising topics that an organization is capable of implementing are considered valuable as business opportunities, two criteria – attractiveness and feasibility – are used for prioritization.

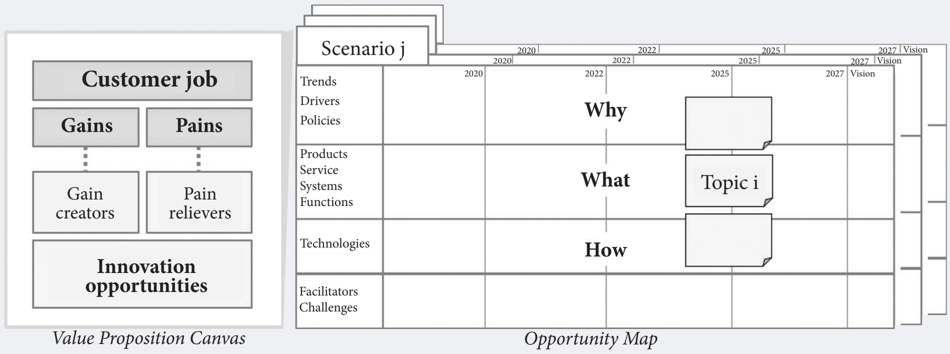
Then, a strategic technology roadmap is established on a selected topic, for which experts' panels are used. The experts use their insight to set a vision for the topic, discuss the current state of the topic, and establish the milestones to achieve the vision based on the current state. During this process, panels often face situations in which all information on the relevant technologies for the topic are not available, particularly in the era of uncertainty and convergence. Nevertheless, a compre-

Figure 1. **Overall Roadmapping Process**



Source: [*Phaal et al.*, 2007].

Figure 2. **Opportunity Map (adapted from the strategic landscape of S-Plan)**



Note: Topic (*i, j*) means *i*-th topic of *j*-th scenario.

Source: compiled by the authors.

hensive understanding of the corresponding technology trends and potential competitors is required for robust planning. Here, patent analyses discover available technology solutions within the target area as well as other areas. In particular, the recent advances in data analytics and visualization allow one to extract useful technical information from a large number of patent documents effectively. Emerging technological trends can be identified in the form of keywords or key concepts from the collection and analysis of topic-related patent documents. On the other hand, patent documents published in other areas can also be analyzed to summarize their trends to be referenced or converged, which supports the discussion during roadmapping. Here, the level of specificity for a strategic technology roadmap may vary by resource constraints and the roadmap's purpose. Figure 3 represents workshop templates for Stage 2. The map on the left is used for detailed planning for each topic, while the map on the right is for an aggregated level planning for all topics of concern.

Stage 3. Planning

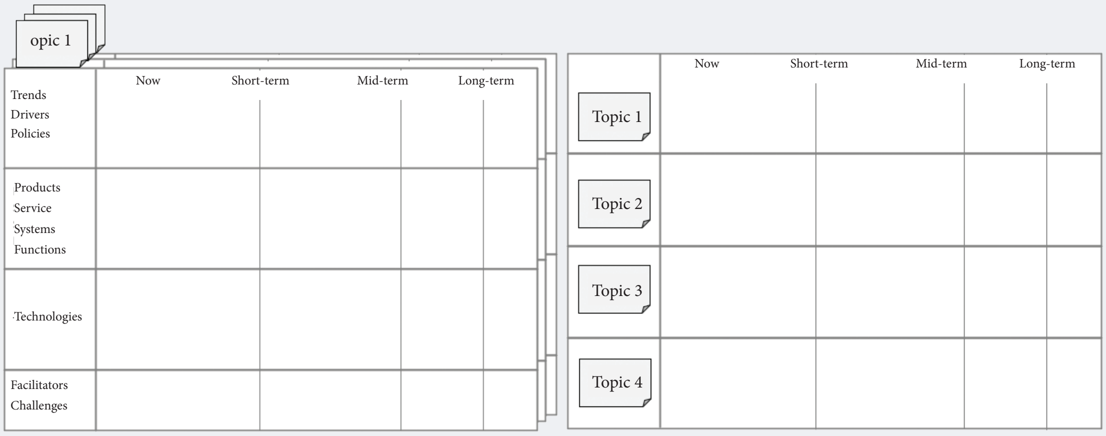
The final stage is aimed at developing a detailed plan to pursue high-priority topics, particularly those focusing on technology planning. The technologies relevant to the topics are evaluated by four selection criteria: importance, urgency, development risk, and technological capabilities. *Importance* evaluates the criticality level of the organization's acquiring the technology. If the technology is likely to have a strong, positive impact on the organization and aligns with the organizational strategy, it will have a higher value. *Urgency* measures how immediately the technology is needed at the organization. *Risk* evaluates the degree of risk associated with the technology; if the technology requires complex technologies and high costs, its development risk will be high. *Capability* indicates the level of technology-related knowledge or expertise within the organization. These criteria can be adjusted to roadmapping contexts. Sub-criteria can be designed, where decision-supporting techniques such as scoring models, the analytic hierarchical processes, or the analytical network processes are used to synthesize experts' evaluation results. Furthermore, data analysis can also support experts' evaluation at this stage. For example, patent analysis can serve as a reference for technological capabilities and impact analysis can serve as a reference for importance. Based on the analysis results, two portfolios are proposed: one to prioritize the items and the other to establish an action plan (see Figure 4).

Case Study

Background

The three-stage workshop-based roadmapping process was performed in collaboration with Hyundai Motor Company, a South Korean automobile company. Recently, the automobile industry has encountered considerable challenges related to a dramatically changing business landscape caused by the emergence of the sharing economy, pressures caused by environmentally friendly automobiles, and the opportunities available for various forms of personal mobility. These unpredictable factors make the industry risky for incumbents but easy to enter for newcomers. Organizations in the industry are introducing roadmapping aggressively to search for new business and technology opportunities and they are investing in their R&D to cope with the expected changes in their industry Accordingly, the automobile industry was suitable for a case study, which was conducted over the course of two months (February and March 2018). The research team played the role of a roadmapping team that designed a process, recruited participants, facilitated the process, provided relevant information, and summarized the roadmapping results. During the process, we observed when and where information needs occurred, what kind of information was required, and how the data needed to be analyzed to support expert's decisions effectively during roadmapping.

Figure 3. **Strategic Technology Roadmap (adapted from the topic map of S-Plan)**



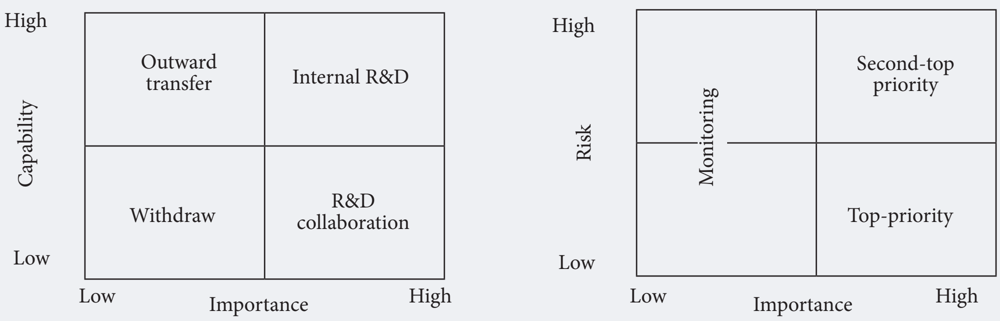
Source: compiled by the authors.

Roadmapping Process

The three-stage roadmapping was implemented using two workshops along with tasks imposed between the workshops. The first and second stages were covered in the first workshop, while the third stage was conducted in the second workshop. The participating team was in charge of technology development related to the noise, vibration, and harshness (NVH) of automobiles and aimed to establish a long-term R&D plan for about 10 years given the new role of NVH technology in future mobility services: in general, a ten-year time horizon is considered to be appropriate for many organizations [*Phaal, Muller,* 2009]. All team members were involved in the roadmapping as a taskforce team. The roadmapping process started from process design, followed by the development of scenarios, identification of opportunities, and the development of strategies along with action plans. Here, short-term opportunities were searched for in the trend analysis of patents and publications, while long-term opportunities were identified from expert discussions. From the requirements of the participating team, the main target for data analysis was set to patents and publications within and outside of the sector. As a result, a standardized process proposed in this study was customized as shown in Table 1.

The first workshop was carried out on February 9, 2018 and was aimed at identifying new business and technology opportunities (Stage 1). Before the workshop, the team requested that future mobility scenarios be prepared because all the team members were engineers and, although NVH technologies can be expected to be influenced significantly by external factors, they needed sufficient time to think about those factors. Accordingly, five scenarios were proposed using three criteria – vehicle control, vehicle ownership, and new vehicles (see Figure 5). Then, to facilitate discussion, customer profiles that described the activities that customers were involved in while using the vehicles were developed for each scenario as well as a value proposition map that investigated the needs and wants expected during the activities. Finally, the participants generated new business and technology opportunities and explained them in terms of why the opportunity is needed, what the opportunities are, and how the op-

Figure 4. **Portfolio Map for (a) Prioritization (left) and (b) Action Plan (right)**



Source: compiled by the authors.

Table 1. **Customized Roadmapping Process**

Workshop	Stage	Experts' insights	Data-driven methods (data sources)
1st round	Ideation	• Value proposition for each scenario • Innovation opportunities in each scenario	• Scenario analysis by identifying trends (public and private reports)
	Selection	• Topic definition based on the opportunities • Topic evaluation using two criteria – attractiveness and feasibility	• Technology trend analysis on the target area (patents and publications data) • Technology trend analysis on the reference area (publications data)
2nd round	Planning	• Technology definition for each topic • Technology evaluation using four criteria – urgency, risk, importance, and capability	• Statistics and portfolio analysis on the evaluation results (evaluation data) • Potential collaboration partner analysis (publications data)

Source: authors.

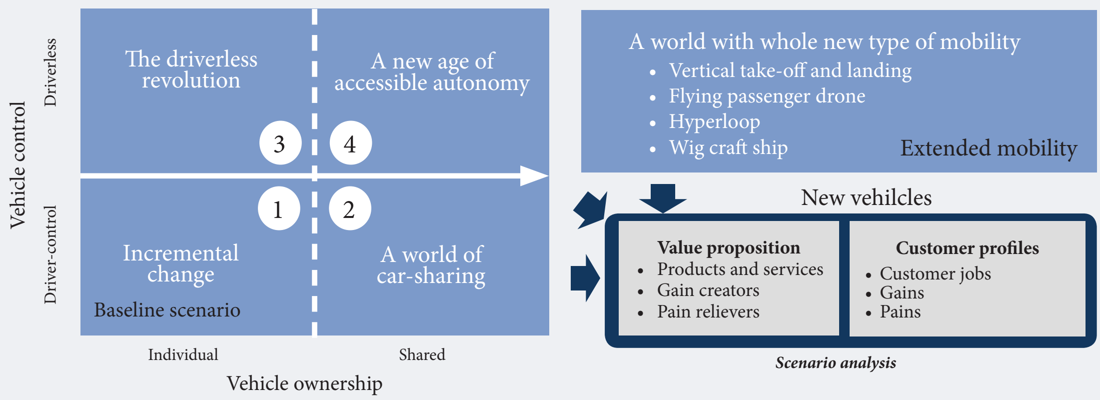
portunity can be pursued (that is, the technologies required to do so).

These opportunities were discussed among participants and similar opportunities were merged, leading to 18 topics (Stage 2). A further evaluation of the *attractiveness* and *feasibility* of the 18 topics led to the selection of 11 topics along with 46 corresponding technologies for detailed planning. Of these, five topics were associated with multiple scenarios and were called G-topics (general-topics), whereas six were scenario-specific and were called C-topics (context-topics). Given the limited number of topics, internal discussions were carried out to choose the topics and technologies for further investigation.

On the other hand, trend analysis results based on patents and publications were provided to the participants for the identification of available technologies within and outside of the sector (see Figure 6). For this purpose, 27,411 publications were collected from the Scopus database. In total, 5,988 patents from the USPTO, 1,181 patents from the EPO, and 329 patents from the KPO were collected on automobile NVH technologies; these were published between January 2016 and March 2018. To summarize the contents of the patents and publications effectively, topic modeling based on LDA[2] was performed. This resulted in nine topics (29 subtopics) from patents and publications. The relationships between the topics proposed during the workshop and the topics obtained from data analysis were investigated by the research team and proposed to the roadmapping participants for reference.

In addition, for each topic, the relevant keywords, the number of relevant documents, the major organizations, and key documents were summarized, as shown in Table 2. We also highlighted hot topics that are gaining more attention and cold topics that are losing attractiveness, which we defined based on the increasing rate of relevant documents, along with outlier patents defined as unique patents in terms of their technological content on the premise that those patents could have the potential to be disruptive technologies. This data analysis process helped the participants understand what opportunities are in line with the main technology trends and, more specifically, obtain a list of patents and publications worth reviewing while investigating each topic.

Figure 5. **Future Mobility Scenarios**



Source: authors.

[2] Latent Dirichlet Allocation.

Table 2. **Partial Topic Analysis Results (door locking apparatus)**

Topic	Door locking apparatus (US-topic5)
Keywords	Position, actuator, locking, movable, lever, movement, lock, positions, latch, move
Document number	589
Key documents	• One motor latch assembly with power cinch and power release having soft opening function (US20170089103A1) • Apparatus and method for actuating a switch or sensor (US20160230427A1) • Twist latch for compartment door (US20170218667A1) • Door lock device for vehicle (US20160340937A1) • Cinching latch assembly for vehicle (US20170306661A1)

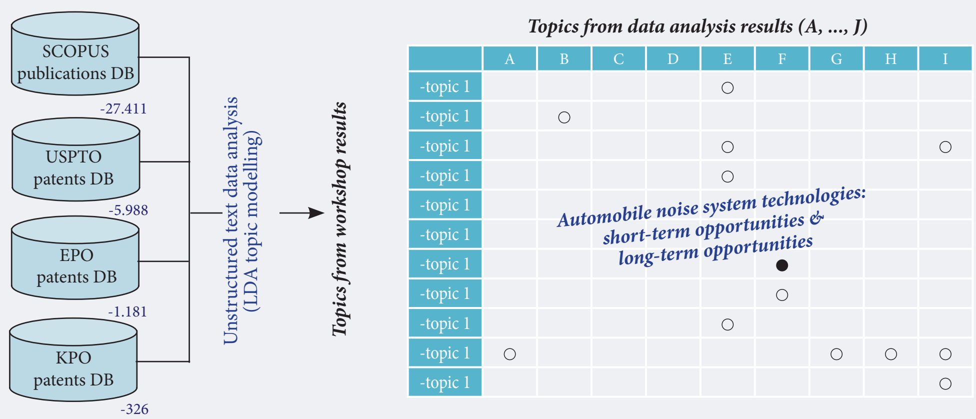
Source: authors.

Furthermore, the participants suggested that recent psychoacoustic technologies could be applied to improve automobile NVH system, particularly for G-Topic 1. However, the topics were outside their areas of expertise, so another round of data analysis was necessary. Focusing on the psychoacoustic technologies, we collected 1,534 publications published from January 2016 to March 2018 from the Scopus database. Again, LDA-based topic modeling was used, resulting in ten topics (40 subtopics). For this study, we focused only on the publication data because the company was seeking collaboration partners in academia, which was the main source of the publications. Again, the research team matched relationships between the 13 technologies for G-topic 1 and ten topics identified during data analysis to help the roadmapping participants introduce emerging psychoacoustic technologies in the NVH system. Furthermore, these patent and publication analyses enabled the participating team to identify potential collaborators for pursuing the topics.

The second workshop, which targeted more focused discussions on the selected topics and relevant technologies, was held on March 29, 2018 (Stage 3). Between the first and second workshops, we asked five key participants to evaluate the 46 technologies associated with the 11 topics using four criteria – urgency, risk, importance, and capability – as well as precedent relationships between the technologies via a technology cross-impact matrix. This task encouraged the participants to think deeply about the topics and technologies and let them search for those technologies individually. This was expected to support discussions in the second workshop. Given the broad scope of the topics, we allowed the participants to leave some questions partly unanswered if they lacked expertise on the technology or failed to collect relevant information. On acquiring the results, the basic statistics of the technology – mean and standard deviation – and technological relationships were used to develop a preliminary technology roadmap for the second workshop, as shown in Figure 8.

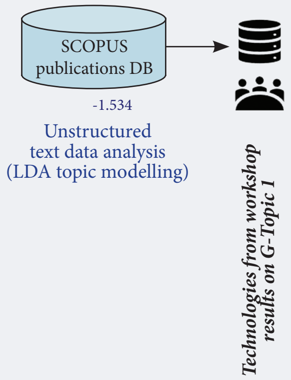
In this workshop, participants presented and discussed various viewpoints, particularly in terms of the technologies with high standard deviations in their evaluation results. An in-depth discussion of the technologies with diverse viewpoints led the participants to share their ideas and reach a consensus. In addition, a first draft roadmap developed based on the evaluation results was presented to be modified according to the discussion results. This preliminary roadmap could have been developed for each topic or for all topics at an aggregated level. As the roadmapping was conducted at the team level, not the organizational level, we put all the topics and relevant technologies onto a single roadmap, as shown in Figure 9. Here, it should be noted that five C-topics were merged into a single topic due to the small number of relevant technologies for each topic. Accordingly, the roadmap included seven topic layers with 46 technologies. FFirst, the technologies were positioned according to their urgency values

Figure 6. **Topic Analysis Results for within the Sector**



Source: authors.

Figure 7. **Topic Analysis Results for Outside the Sector**



Topics from data analysis results on psycho-acoustic technologies

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
G1-1								●		
G1-2			●		●					
G1-3								●		●
G1-4	●	●						●		
G1-5				●			●	●		
G1-6										
G1-7								●		
G1-8						●				
G1-9								●	●	
G1-10		●	●			●	●	●	●	●
G1-11									●	
G1-12					●					
G1-13		●			●					

Automobile noise system technologies: Recent psycho-acoustic technologies

Source: authors.

Figure 8. **Technology Evaluation Results**

a) Basic statistics on the evaluation results (partial)

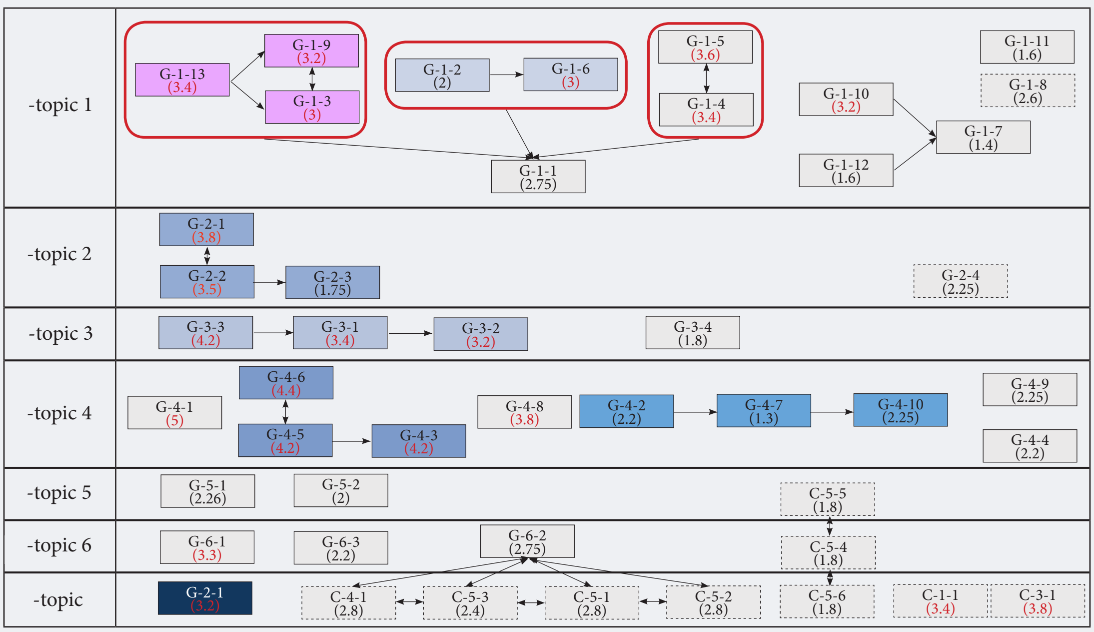
Urgency			Development risk			Importance			Technological capabilities		
Mean	Std	Rank	Mean	Std	Rank	Mean	Std	Rank	Mean	Std	Rank
2.75	1.5	24	4	0	2	3.8	0.447213595	9	2.75	1.483239607	7
2	1	37	3.6	0.547722558	6	3.6	0.547722558	15	1.4	0.547722558	40
3	1	19	2.4	0.894427191	35	3.4	0.547722558	25	1.75	1.140175425	30
3.4	1.140175425	10	3.6	0.894427191	6	3.6	0.894427191	15	1.2	0.447213595	45
3.6	0.894427191	8	3	1	21	3.8	0.447213595	9	1.6	1.341640786	36

b) Technology cross-impact matrix (partial)

	G-1-1	G-1-2	G-1-3	G-1-4	G-1-5	G-1-6	G-1-7	G-1-8	G-1-9	G-1-
G-1-1										
G-1-2	○←→→-									
G-1-3	→←→→-	→○→-								
G-1-4	○←→→-	○○-○-	←○-←-							
G-1-5	○←→→-	○○-○-	←○-←-	○○→○-						
G-1-6	○○→-	○○←→-	←→-○-	○→→→-	○→→→-					

Source: authors.

Figure 9. **Technology Roadmap**



Source: authors.

Table 3. **Aggregated Evaluation Results at the Topic Level**

Topic	Urgency			Risk			Importance			Capabilities		
	Mean	**Std**	**Rank**	**Mean**	**Std**	**Rank**	**Mean**	**Std**	**Rank**	**Mean**	**Std**	**Rank**
-topic 1	2.74	0.52	10	2.95	0.30	7	3.30	0.22	7	2.01	0.67	7
-topic 2	2.75	0.68	9	3.60	0.68	1	2.95	0.54	9	1.75	0.85	9
-topic 3	3.15	0.89	5	2.10	0.52	11	3.55	0.62	4	2.40	0.68	2
-topic 4	3.26	0.49	3	2.78	0.43	8	3.79	0.43	3	2.15	0.62	6
-topic 5	2.80	0.57	6	3.20	0.76	3	2.90	1.24	10	2.25	0.87	4
-topic 6	2.77	0.91	8	3.00	0.91	6	2.73	0.89	11	2.27	0.98	3
-topic 1	3.40	1.52	2	3.40	1.82	2	4.20	0.45	1	2.00	1.00	8
-topic 2	3.20	1.10	4	2.20	1.10	10	4.00	1.22	2	3.40	1.67	1
-topic 3	3.80	1.30	1	2.50	1.73	9	3.40	1.14	6	2.25	1.26	4
-topic 4	2.80	1.30	6	3.20	1.48	3	3.20	1.10	8	1.25	0.50	11
-topic 5	2.17	1.48	11	3.20	1.04	3	3.53	0.49	5	1.67	0.53	10

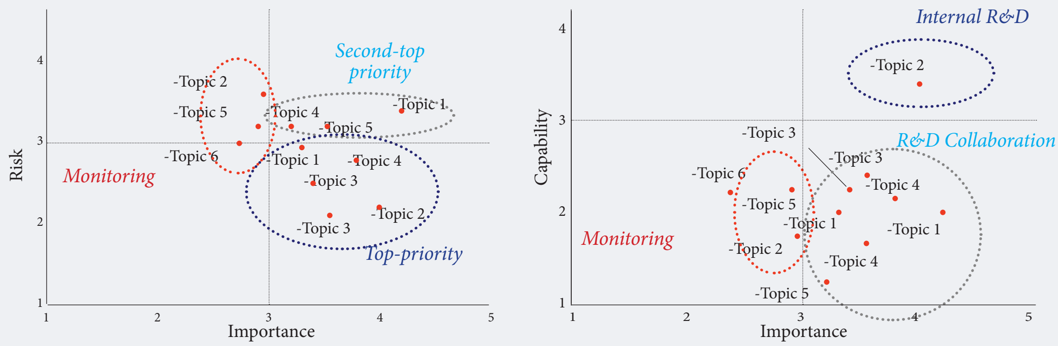
Source: authors.

and the links were established based on the values in the cross-impact matrix, where their importance values were presented as reference information. The participants reviewed the first-cut roadmap and adjusted values and positions based upon mutual agreement. Adding or deleting more technologies was allowed at this stage, although it did not occur in this case study.

Finally, the technology evaluation results were aggregated by topic (see Table 3), based upon which portfolio map types were developed – one for prioritization and another for action plans as shown in Figure 10. With the average index value to separate high and low space in the map, five out of 11 topics (G-Topic 1, G-Topic 3, G-Topic 4, C-Topic 2, and C-Topic 3) were positioned in the fourth quadrant of the prioritization map, signifying top priorities of development. Among these five topics, four (G-Topic 1, G-Topic 3, G-Topic 4, and C-Topic 3) were located in the fourth quadrant, while only C-Topic 2 was in the first quadrant of the action plan map. Thus, an R&D collaboration strategy was recommended for the first four topics, producing an industry–academic collaboration lab funded by Hyundai Motor Company. Internal R&D was designed for C-Topic 2.

When investigating the relationships between short-term emerging topics identified from the patent and publication data analysis and long-term promising topics identified from expert insights, we found that improving the internal capabilities in E, F, and I, which are associated with the five top-priority topics (G-Topic 1, G-Topic 3, G-Topic 4, C-Topic 2, and C-Topic 3), would be greatly helpful in preparing for the future and gaining competitive advantages. Furthermore, we also found that G-Topic 1 could benefit significantly from recent developments in psychoacoustic technologies, since the topic is characterized as a technology convergence between NVH and psychoacoustic technologies. Therefore, a link between technologies for G-Topic 1 and the topic analysis results for psychoacoustic technologies were considered to identify potential collaboration partners.

Figure 10. **Portfolio Maps**



Source: authors.

Discussions

Recommended situations for applying the method

With the emergence of disruptive technologies and innovative business models, companies are challenged by ongoing technological revolutions and rapidly changing business conditions, leading to an increasing level of uncertainty. The proposed approach that integrates data-driven methods with expert insights is useful particularly for technology planning under such uncertainty. Expert insights are key to long-term planning by setting a vision and strategy for the organization, while data-driven methods enable users to understand and prioritize innovation opportunities made available by recent disruptive technologies. In addition, the data-driven methods help one to collect and synthesize expert insights systematically. Under uncertainty, experts may have different subjective opinions on the same candidate opportunities, possibly due to their different experiences and knowledge of the target technological domain. Thus, it is essential to integrate their knowledge for reliable decision-making, where data-driven methods provide objective information around candidate opportunities.

Bias

Despite the value of combining expert insights with data-driven methods, using several data-based methods is not always advantageous because data collection and analysis usually requires a huge amount of time and effort, thus delaying the roadmapping process. On the other hand, agile roadmapping is valuable under uncertainty, capturing value in short-term initiatives. Accordingly, understanding the needs for data analysis is indispensable for designing the roadmapping process along with accessing the right data and having the most qualified people as roadmapping participants. Notably, said participants may depend too much upon data analysis results, thus limiting their creativity in developing new ideas. Hence, an optimal use of data analysis results for effective roadmapping must be determined. Furthermore, additional data sources necessitate a process for selecting reliable ones, constructing a balanced portfolio, and developing effective analysis methods — issues worth addressing.

Implications for theory

While most existing studies on roadmapping focused either on workshop-based or data-driven approaches [*Park et al.,* 2020], this study emphasized the integrated use of expert insights and data-driven methods. On the one hand, opportunity capture by eliciting knowledge from experts is important since it involves tacit knowledge sharing. On the other hand, opportunity capture by analyzing technological and market data is also significant given that it enables one to generate, identify, and evaluate more ideas. How to best combine the two types of knowledge – one from expert insights and the other from data analysis – can be an important topic for roadmapping research.

Implications for practice

The research findings offered several implications for practice in the field of roadmapping. First, data analysis needs largely occurred in three areas: understanding research trends within the sector, identifying available technologies in another relevant sector, and collecting and summarizing expert opinions. With today's increased technological complexity and emerging breakthrough and/or converging technologies, data analysis is essential to improving roadmap quality. Furthermore, offering data analysis results may enhance communication among experts. By providing objective information, a data analysis prevents a single person, usually a senior manager, from dominating the discussion. Future research is needed to examine how the data analysis results can be used to enhance roadmapping quality.

Application notes

Before initiating a roadmapping process, it is necessary to clearly define the scope and purpose of such an endeavor including a plan of how the outputs will be used. Designing a roadmapping process within a limited budget is also critical for successful roadmapping, particularly for a hybrid method where both experts and data-driven approaches are used. Regarding the experts, the most motivated and qualified people need to be identified to be engaged in roadmapping. Using appropriate templates can help to elicit and share expert knowledge. As to the data, the data analysis results should be able to fill in the knowledge gaps of the experts. Therefore, the data analysis needs, procedures, and results are recommended to be carefully planned. Otherwise, the analysis results cannot be integrated into workshop-based roadmapping. The cost and benefit of analyzing each type of data should be considered as well to optimize the use of data-driven methods.

Lessons from the case study

First, expert insights produced creative ideas with information about relevant projects (past and ongoing) and about learning from them, whereas data analysis results mostly offered feasible ideas regarding competitor trends and available technologies in other sectors. These two approaches are complementary, but analysis results must be provided in a correct form at the correct level of detail for data analysis results to be useful for experts. Recent data analysis and visualization techniques can be introduced to effectively use data. Second, most computer-based roadmapping literature mainly considered two data sources as targets for analysis: patents and publications, which are useful in analyzing past trends. However, more data sources that present competitors' plans (e.g., news and YouTube) and/or expert insights from outside of organizations (e.g., LinkedIn and podcasts) will be available, going beyond traditional analyses of patents and publications. These data sources can be linked to generate more valuable implications.

Areas for future research

The workshop observation raised several research gaps to address, suggesting future research directions. First, in the case study, the data analysis needs stem from roadmapping at a team level, and different needs could be addressed via roadmapping at the organizational level. The needs may also vary by roadmapping context, such as long-term versus short-term planning, product versus service development, defining versus solving problems, and internal R&D versus collaboration strategies. According to [*Schimpf, Abele,* 2019], data sources useful for roadmapping include external roadmaps, associations, market analyses, suppliers, customers, users, research organizations and universities, competitors, consulting companies, legislation, journals, and media. Useful public and private data sources for context-specific roadmapping must be studied further. Second, continuous research is needed to develop hybrid roadmapping processes and methodologies.[3] Combined with newly available data sources and methods, the roadmapping process can become more efficient. Moreover, a hybrid process can also benefit significantly from introducing roadmapping systems, which enables systematic data collection, sharing, and elaboration across organizational units [*Amati et al.,* 2020]. It enables the integrated application of those methods and easy updates of roadmaps [*Phaal et al.,* 2004; *Lee, Park,* 2005]. Thus, future research is necessary to create a framework for developing, evaluating, and improving a hybrid roadmapping process. Finally, future research must address challenges by the timely updating of roadmaps to keep them alive. Changing business environments and emerging promising technologies can be monitored continuously via data collection and analysis. How to evaluate a roadmap's status and how to choose when to revise it need further investigation.

Conclusions

This study discussed how to combine data-driven methods with expert insights during roadmapping. Today's business environment is characterized as being full of uncertainties. On the one hand, the rapid emergence of disruptive technologies[4] has changed the way organizations do business. On the other hand, social pressures on technologies or other unpredictable social changes such as the present pandemic also make it hard for an organization to plan the future. Accordingly, a workshop-based approach can help an organization to quickly respond to the changing environment, enabling agile roadmapping, and allowing organizations to also establish long-term planning based on expert insights. Here, an appropriate use of data is expected to supplement limited knowledge during the expert-driven roadmapping.

In this study, a workshop-based roadmap aiming for 10-year technology planning to deal with uncertainties was implemented in collaboration with Hyundai Motor Company. We focused on the data analysis needs of the workshop participants and the way the analysis results were used in participants' decision-making. The research findings indicated that discussions among participants were facilitated by the use of data analysis results: they were useful in having a forward-looking perspective for the ideation stage and collecting diverse opinions to develop a first-cut roadmap for the selection stage. For the planning stage, data were useful for understanding emerging trends within the sector and identifying available technologies and collaboration partners outside of the sector. Consequently, this study contributes to the advances in roadmapping methodologies by suggesting the necessity of a hybrid approach that combines data analysis results and expert insights. Furthermore, this is one of the few studies on corporate roadmapping in a real setting, and hence, it can have practical contributions as well.

Despite its meaningful contributions, this study has several limitations. First, only a single case study was conducted in each of the contexts of 1) team-level roadmapping; 2) the automobile industry; and 3) the Asian context. The level of hard data required for robust roadmapping may change due to various factors such as the purpose of a given roadmapping, industry condition and organizational and possibly national culture. More cases are needed to improve the external validity of the research findings. Second, most of the findings were derived from observations on the roadmapping process itself. Although an ethnographical approach was adopted in this study, interviews with participants or surveys on data analysis needs during roadmapping across organizations could produce more meaningful insights. Accordingly, further analysis on the before- and after-roadmapping stages can be conducted to understand data needs and satisfaction. Finally, this study discussed how to integrate data-driven methods with expert insights but failed to propose a new roadmapping framework to integrate a data-driven approach with expert insights. Recent advances in data analysis techniques along with the emergence of numerous data sources are expected to provide various implications to support expert ideation and decision-making during roadmapping. Future research will continue to address those issues.

[3] Various methods have been applied to support roadmapping, including technology radar, portfolios, creativity methods, strategy maps, balanced scorecards, scenario analyses, quality function development, technology maps, maturity models, regression, and Delphi studies [Schimpf, Abele, 2019].

[4] Among them are self-driving cars, robots, artificial intelligence, big data, the Internet of Things, mobile technology, virtual reality, blockchain, FinTech, drones, 3D printing, digital healthcare, bio-healthcare, and new materials and energies.

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Knowledge Co-Creation Roadmapping for Future Industrial Visions: Case Study on Smart Infrastructure

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Abstract

This paper proposes a knowledge co-creation roadmapping tool for knowledge creation in future-oriented discussions for members of competing firms with the aim of co-creatively envisioning the future of the industry. This approach adapts the roadmapping method for knowledge creation, thus building a communication infrastructure for discussing future plans beyond an organization (i.e., participants are from competing companies). Knowledge co-creation roadmapping could be commissioned for an open industry organization consisting of members sent by individual companies interested in overcoming obstacles to development. We put our method into practice with the subcommittee of the Engineering Advancement Association of Japan and set the subject as "The Future of Smart Social Infrastructure", a theme involving multiple stakeholders. We were able to draw up a vision of smart technology on the basis of the insights gained through the roadmapping activities. These results demonstrate the effectiveness of our method in terms of acquiring knowledge that could not be obtained by our own company or a single industry organization alone..

eywords: strategy design; co-creative future design; roadmapping; knowledge creation; future of social infrastructure; smart technologies

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In the modern landscape, it is crucial for social infrastructure to increase value by utilizing advanced technologies related to IoT, artificial intelligence, and robotics[1]. Regarding the "smartness" of industry and society, the SCIAM[2] [*Neureiter et al.,* 2014], RAMI 4.0[3] [*Zezulka et al.,* 2016], and SCSP[4] [*Koshizuka et al.,* 2018; *Santana et al.,* 2018] models have been proposed. These are mainly related to the promotion of ICT and IoT and to the standardization of implementation methods and standards for these systems. At the same time, in order to make social infrastructure smart, it is necessary to comprehensively study the connectivity among hardware infrastructure and the relationship between software infrastructure and advanced technologies when considering which functions the hard infrastructure will require in the long-term future. It is not practical for each company in an industry to have myopia in the sense that the future is envisioned only within the scope of its own current business model, rather, multiple stakeholders should be involved in planning for the future [*Smith et al.,* 2010].

In Japan, the Engineering Advancement Association of Japan (hereinafter ENAA), an industry organization, brings together different companies involved in social infrastructure. Even though rival companies are typically present at these meetings, information sharing and joint discussions are encouraged to develop together as an industry. ENAA has also established a subcommittee on smart social infrastructure, where interested companies send their employees to discuss future business trends. The purpose of the activities of the subcommittee is to conduct research on "smart social infrastructure", which is a solution to the problems of social infrastructure with smart technology, from the perspective of vision and technology. This type of forum plays a very important role in overcoming the myopia of management and discussing a long-term vision for the development of the industry. However, if such forums are not managed effectively, they will not be able to function well due to potential problems that may arise in an assembly of rival companies in the same industry. The following issues are expected to occur when people with different interests get together to come up with ideas:

(i) knowledge sabotage activities, such as hiding ideas that are detrimental to one's own organization [*Serenko,* 2019],

(ii) excessive divergence of discussions by focusing on the individual interests of each company [*Chambers,* 2004], and

(iii) limited knowledge space by exchanging opinions from only one's own area of expertise, resulting in a novel "no ideas emerge" conundrum [*Shirahada, Hamazaki,* 2013].

These potential challenges to future industry conceptualization by industry organization members arise from the inadequate functioning of organizational knowledge creation through the interaction of tacit and formal knowledge among different company members. At present, appropriate countermeasures have not been adequately studied.

In this paper, we propose a new knowledge co-creation roadmapping method that integrates the SECI[5] model, which describes the process of organizational knowledge creation [*Nonaka*, 1994], and the roadmapping method, which is a communication infrastructure for discussing future plans.

Literature Review

Roadmapping

In a roadmap, various inputs are arranged into a time-based, multi-layered chart that aligns various functions and perspectives within an organization to form a generic "strategic lens" through which the strategic evolution of the business can be viewed [*Gordon et al.,* 2020; *Phaal et al.,* 2004]. The roadmap has also been extended in scope for different levels of analysis, supporting strategies at the national, sectoral, or firm level that require different levels of granularity [*Amer, Daim,* 2010; *Gordon et al.,* 2020; *Phaal, Muller,* 2009]. Specifically, this is a process of identifying gaps between markets, technologies, and products/services by sharing the perspectives of multiple stakeholders and creating an integrated pathway to bridge these gaps [*Daim et al.,* 2018; *Daim, Oliver,* 2008; *Gerdsri et al.,* 2009; *Hansen et al.,* 2016; *Lee et al.,* 2013; *Sauer et al.,* 2017; *Wells et al.,* 2004]. This technique can be used to conceptualize strategies in a participatory manner [*Kerr et al.,* 2013] as well as to facilitate consensus building [*Kerr et al.,* 2019] for stakeholders to advance their creative ideas and visions.

Roadmapping usually consists of four stages: the team start-up and planning stage, the input and analysis stage, the integration and charting stage, and the implementation and periodic review of the results of consultations stage [*Gerdsri et al.,* 2009]. During the input and analysis phase, workshops are conducted, usually with multiple stakeholders, to gain, share, and create knowledge. At the charting stage, while various arrangements are

[1] This infrastructure encompasses both the hardware side, such as buildings and equipment, and the software side, such as communication and control technology. Both the hardware and the software aspects of infrastructure are expected to combine with IoT, artificial intelligence, and robotics to promote smartness (optimization and autonomy) and create new services for client companies and the everyday people who are the end users.

[2] Smart City Infrastructure Architecture Model.

[3] Reference Architecture for Industrie 4.0.

[4] Smart City Software Platform.

[5] Socialization, Externalization, Combination, Internalization.

possible [*Cuhls et al.,* 2015; *Kerr et al.,* 2012; *Lee et al.,* 2012; *Lee, Park,* 2005; *Yoon et al.,* 2008], for the purpose of our work we utilize a framework that includes markets, products, services, and technologies as layers along with a timeline [*Phaal et al.,* 2005]. Using this framework, we can ask ourselves: where are we now, where do we want to be, and how do we plan to get there (what is our goal)? The members of the group work together through joint discussions to determine the best way to get there (how do we get there?).

Roadmaps have been the focus of technology management and foresight research since the 2000s as an effective communication platform for future-oriented discussions [*Gordon et al.,* 2020]. The themes that have been applied are broad and include new product development [*Petrick, Echols,* 2004] and prediction of disruptive technologies [*Phaal et al.,* 2011; *Walsh,* 2004]. In addition, roadmaps have been actively utilized as a strategic management tool [*Fenwick et al.,* 2009; *Gerdsri,* 2007; *Gerdsri, Kocaoglu,* 2007; *Phaal et al.,* 2006; *Toro-Jarrín et al.,* 2016]. However, to date there have not been sufficient roadmapping efforts in industry organizations. In addition, the use of roadmaps in industry organizations requires members of competing companies to share their knowledge with each other and create new knowledge, which can be problematic. Although one roadmapping study [*Phaal et al.,* 2005] touched briefly on the knowledge creation process, to the best of our knowledge, there has been no prior work that focused on the development and application of roadmapping with a consideration of knowledge creation in future-oriented discussions, nor shown its effectiveness empirically.

Organizational Knowledge Co-Creation

The SECI model [*Nonaka,* 1994] is an organizational knowledge creation process model. It assumes that new knowledge is generated through the interaction of tacit and formal knowledge, and that organizational knowledge is created through the processes of Socialization, Externalization, Combination, and Internalization. The steps of the knowledge creation are explained as follows.

The first step, Socialization, is the mode of converting tacit knowledge through interaction between individuals. This is the process of acquiring the tacit knowledge of another through the sharing of experiences. The second, Externalization, is the mode of transforming tacit knowledge into formal knowledge. This is a process of transforming the tacit knowledge of individuals into formal knowledge through the media of language, images, and other means of expression and developing it as group knowledge. The third, Combination, is the mode of systematizing and conceptualizing group knowledge into formal knowledge by linking concepts and modeling them, or subdividing concepts into different categories. The fourth, Internalization, is the mode of transforming formal knowledge into tacit knowledge. This is the process of acquiring tacit knowledge through actions. The creation of these four modes is in an upward spiral, in which knowledge is created, increasing in its quality and quantity, in relationships from individual to individual, from individual to group, from group to organization, and from organization to individual again. This process is the organizational knowledge creation described by the SECI model.

Nonaka & Toyama developed a knowledge creation dynamic model [*Nonaka et al.,* 2008; *Nonaka, Toyama,* 2005] that identifies vision, driving objectives, intellectual assets, regular communication [*Nonaka et al.,* 2000; *Nonaka, Konno,* 1998], and environment as the factors that continuously and effectively advance the SECI process. A vision is the ideal future we want to achieve for our organization. Driving objectives are specific goals and codes of conduct to drive the flow of the SECI process. Intellectual assets are the accumulation of knowledge generated through the SECI process. Regular communications are the foundation through which SECI processes flow and knowledge is generated. The environment is an ecosystem that connects an organization to various external organizations. The intrinsic knowledge is created when the organization works in the environment, comes into contact with the knowledge of the environment, takes it into the organization, and interprets it. As an industry organization, we need to take the non-hardware knowledge that we are lacking and interpret it as intrinsic knowledge from the environment, which is a necessary process for implementing future discussions on smart social infrastructure in conjunction with hardware knowledge. There is an affinity between discussions on the future of social infrastructure and organizational knowledge creation in the sense that conducting such discussions results in the creation of knowledge. In addition, it is also important that members' roles are not fixed within the organization, but rather complement each other voluntarily to provide information and generate ideas through knowledge co-creation efforts [*Lakhani, von Hippel,* 2003].

Stages of Knowledge Co-Creation Roadmapping

With the aim of advancing the organizational knowledge creation process and collaboratively considering the future of various social infrastructures, we have developed a knowledge co-creation roadmapping method that features (i) sharing thoughts and feelings, (ii) knowledge acquisition and common experience in the field, (iii) creating a roadmap with acquired knowledge, and (iv) report preparation. Through them, we aim to achieve the vision of the organization. The details of these four steps are as follows.

Sharing thoughts and feelings. The members of the subcommittee are dispatched by each company based on an understanding of the theme and purpose of the activity in the recruitment guidelines, either at the request of the member companies belonging to the industry organization or upon an application by their own employees. When the gathered members of the subcommittee formulate a specific activity plan, they share their thoughts and awareness of the issues by writing in their position paper and presenting why they wanted to participate in the activities, what they want to do in terms of specific activities, and what they hope to gain through these activities. In order to foster a spirit of collaboration, the members are asked to provide materials and information that may be useful in their activities. These will then be used to formulate specific plans and to refine the sub-themes of the activities.

Knowledge acquisition and common experience in the field. After conducting a survey of the published literature based on the sub-themes of the activity, the members will organize a research visit and visit the actual site. Through these site visits, each person acquires tacit knowledge through statements made by the person in charge of the site, by seeing and experiencing the actual equipment and operations, and what currently happens. During this site visit phase, multiple locations are visited to compare the similarities and differences between them, or multiple visits to the same site are made to investigate the evolution and improvement of the content over time. Members will also ask experts to present lectures. Through explanations and questions and answers from the experts, we acquire tacit knowledge of their perceptions and value judgments. Over the course of several presentations, we listen and compare the similarities and differences in the perceptions and value judgments of the experts, as in the case of a site visit. To address the limitations of the knowledge space, we implement an approach that provides more opportunities to see the field, gain knowledge from experience [*Kolb et al.,* 2000], and synthesize the opinions of experts.

Creating a roadmap with acquired knowledge. After visiting the sites and listening to lectures from experts, the members discuss their findings and the inferred causal relationships with each other to understand the knowledge created by each other as collective knowledge. The expressed findings and causal relationships, as well as the results of the discussions and interpretations, are further discussed and interpreted by applying the roadmapping technique. Roadmapping with this acquired knowledge will be mapped at the level of sub-themes within the theme of smartness of the social infrastructure.

Report preparation. The results mapped in each sub-theme are integrated to create a full report on the theme as explicit knowledge. During this integration process, the position, relationship, and consistency among each sub-theme are considered, and a unified and consistent report on the theme is created. In addition, we share the reports with other members so that they can learn about the content and bring it back to their companies for the creation of new businesses and improvement of existing businesses.

Organizational Knowledge Creation Activities in Industry Organizations

Knowledge co-creation roadmapping can be summarized through the lens of the SECI model as follows.

- Socialization: Sharing the participants' thoughts and awareness about the issues, formulating specific action plans, and refining sub-themes.
- Externalization: Seeking the essence of the problem through case studies, Q&A sessions, and discussions and elaborating upon the causes and solutions of each problem.
- Combination: Systematizing the causes and solutions of each problem through roadmapping.
- Internalization: Compiling a report in which the results are reflected in one's own way and then bringing it back to the company.

Reviewing the subcommittee activities of the industry organization (ENAA) through the SECI model, each mode can be organized as follows. *Socialization* is the stage in which each person implicitly shares thoughts and awareness of problems through public information selected by each person, sharing perceptions and value judgments of experts through lectures and Q&A sessions, sharing experiences through the comments of the person in charge in the field, and observing actual facilities and operations. *Externalization* is the stage in which each person prepares a personal report and a group report through internal discussions in the subcommittees and working groups based on the results of the case studies. *Combination* is the stage of systematizing the expressed findings, causal relationships, and implications by using a specific framework. *Internalization* is the stage which is equivalent to practicing corporate activities using the tacit knowledge that one has about the situation of each company.

In order to make the SECI process spiral upwards continuously, we need to:

- take into account the characteristics of the industry organization,
- study and investigate the smartness of social infrastructure by taking advantage of its strength in the field, the actual thing, and the reality,
- consider the importance of common experiences such as site visits and lectures by experts,

Our aim here is to introduce a basic framework to facilitate the flow of the SECI process in order to overcome the characteristics of poor conceptualization and systematization. By taking these points into account, we have sought to take advantage of the unique behavioral and thinking characteristics of our industry businesspersons and engineers and overcome their weaknesses. Each element of the knowledge creation dynamics model, taking into account these characteristics, can be summarized as follows.

- The vision is to elucidate and conceptualize the smartness of social infrastructure,

- The driving objective is to "work together to become the leader of each company".
- The knowledge assets are reports of each year, lecture materials, and materials published by government agencies.
- The communication tool is monthly meetings of the subcommittees and working groups, site visits, lecture meetings, and online (email, shared cloud) services.
- The environment is a network of member companies and their networks that send subcommittee members, the neutral role of the industry organization known as ENAA, friendly relations with experts and sites, and access to previous research by academic research institutions.

Application of the Knowledge Co-Creation Roadmapping Method

Application Procedure

In this paper, we report on two workshops we conducted based on the roadmapping procedure for service organizations developed by [*Wells et al.,* 2004]. During the planning phase, we discussed the core issues in the social infrastructure sector and agreed with the members that they are workforce supplementation measures. The first sub-theme, Theme I, was roadmapping in the field of social infrastructure construction by solving problems through smart technologies from the perspective of labor force complementation. The second sub-theme, Theme II, was roadmapping of the operation and maintenance of social infrastructure after construction was completed from the viewpoint of the life cycle of social infrastructure.

These steps are shown in Figure 1. The blocks in the outer four corners follow Wells et al.'s [*Wells et al.,* 2004] road mapping procedure for service organizations, while the knowledge co-creation road mapping, which consists of four steps, is depicted in the center. The description of its stages and their equivalents for the SECI model are presented in Table 1.

These four steps are moving clockwise in principle. However, the arrows connecting (ii) Acquiring knowledge and (iii) Co-creating visions indicate an iterative workflow aimed at clarifying the future vision, while the arrows connecting (i) Sharing thoughts and (iv) Documenting visions indicate a cross-referencing of thoughts and gained foresight for the introspection process.

These four steps can be viewed as Figure 1 through the lens of SECI model, however, the difference from SECI model is that knowledge co-creation roadmapping is a method for future-oriented planning with co-creating knowledge beyond an organization (i.e., participants are from competing companies).

The participants were all members of the ENAA's subcommittee (the maximum number of participants was 17). The members participated in the working groups of their respective sub-themes, starting with Theme I and then continuing to Theme II. In creating roadmaps, we initially received a lecture on the basic content and procedures from an expert on roadmapping. First, the members shared knowledge of basic social and technological trends based on open literature, site visits, and lectures from experts. In the forecasting approach, a list of elements was created and then these elements were clustered. Specifically, the members came up with ideas about related technologies, services, social trends, etc., wrote them on sticky notes, and then grouped them together and extracted the main elements. Next, a matrix between adjacent layers was constructed using the linking-grid method and the members extracted the strongest combinations of relationships by evaluating the strength of the relationships between the elements. A hierarchical map showing the relationship between the extracted elements and their relationships was created as an artifact of these works and a backcasting approach was used to depict the future vision from the social and technological aspects and discuss the potential solutions. Finally, considerations from both the forecasting and backcasting perspectives were integrated and a roadmap including a timeline was created.

The approximate time required for the roadmap preparation in Theme I was six hours for group discussions including the extraction of the elements (two three-hour sessions) and three weeks for the facilitators to organize the roadmap. The appropriate time in Theme II was two days for group discussions and one day to organize the roadmap.

Table 1. **Stages of Knowledge Co-Creation**

Stage of the process	Description	Equivalent stage according to SECI model
1. Sharing thoughts	Sharing thoughts, feelings, and awareness of problem	Discussing important issues among members during the planning stage
2. Acquiring knowledge	Acquiring knowledge and having common experience in the field	Acquiring tacit knowledge through lectures from experts or site visits
3. Co-creating visions	The tacit knowledge acquired by each person is converted into collective knowledge through discussion among members	Mapping findings and causal relationship for each theme through discussions among members
4. Documenting visions	Integrating and formalizing collective knowledge	Preparing the report on the theme and sharing the results of roadmapping with members to respond to the important issues

Source: authors.

Evaluation

To analyze the effectiveness of our knowledge co-creation roadmapping, we administered a questionnaire to all participants at the end of the exercise. The research population consisted of 17 members of the subcommittee (n = 17) who had been active in subcommittee for at least one year between April 2017 and March 2020. We requested responses to the survey by email after the final meeting at the end of FY2019 (March 2020) and eventually received responses from all 17 participants. The questions were based on four perspectives: (1) the results of the research, (2) the process of the research, (3) objective evaluation, and (4) the effectiveness of the roadmapping.

Results of the research. These questions referred to the level of satisfaction with the overall knowledge gained from the early to late stages of the research activities, including the significance to the individual of the explicit findings (e.g., the reports) and the implicit knowledge gained by each person.

Process of the research. These questions referred to the evaluation of common understanding on the subject gleaned from interim document reviews, interviews, field research, and interpretation of findings.

Objective evaluation. These questions referred to the level of achievement of each of the characteristics of the knowledge co-creation roadmapping (process, tools, outcomes, and initiatives).

Effectiveness of the roadmapping. These questions referred to the helpfulness of the process, its usefulness, its effectiveness in forming collective knowledge, and its overall effectiveness.

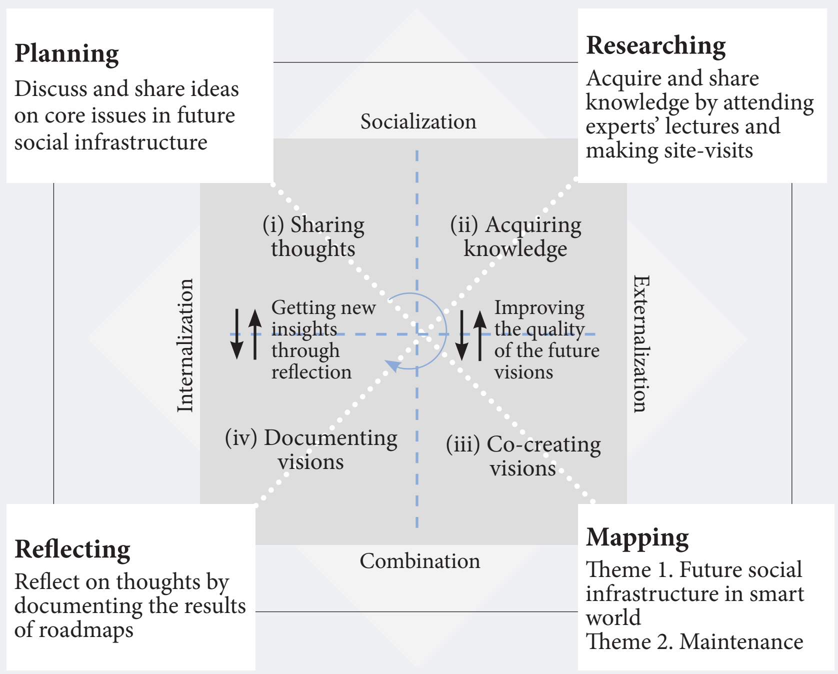
The questions were pre-coded and open-ended questions using a five-point Likert scale. In our analysis of the responses, we carried out statistical processing with the aim of investigating satisfaction. We also carried out primary and secondary coding on the free statements based on the inductive coding method [*Gioia et al.*, 2013]. Our analysis of the responses to the open-ended questions was focused on (1) the results of the research and (2) the process of the research, and we analyzed each person's impressions of the knowledge creation activities of the subcommittee. This enabled us to assess the overall trends in satisfaction with the knowledge co-creation roadmapping activities, after which we extracted individual specific ratings from the results of the free writing analysis.

Results

Roadmap as a Deliverable

Figure 2 shows an example of a detailed roadmap produced in Theme I. The roadmapping activity of social infrastructure construction was carried out with a focus on smart infrastructure construction to respond to the social trend of declining birth rates and an aging population in Japan and the consequent shortage of human resources. The total number of elements extracted by the group KJ method[6] was 78, and these were classified into three types: "elemental technolo-

Figure 1. **Outline of Knowledge Co-Creation Roadmapping**



Source: authors.

[6] Named by its creator, Jiro Kawakita, KJ is a technique for systemizing subjective views of group discussion participants.

gies", "services", and "social trends". Each type is summarized as follows:

- The elemental technologies were further grouped into "sensing devices and communications", "assistants", "robotics", "AI", and "virtual".
- The services were grouped into "systematization", "work efficiency (visualization)", "support for foreign workers", "support for women and the elderly", "automation of general work", "automation of skilled work", and "planning and operation".
- The social trends were grouped into "optimization of human resources", "creation of a database", "work style reform", and "health and safety".

The resulting knowledge implied by the Theme I roadmapping activity was as follows. The number of IoT-based services will expand due to higher battery capacity, lower costs, and smaller devices. With the spread of low-power wide-area (LPWA) technology, 5G, and quasi-zenith satellites, the location restrictions in terms of the communication environment are disappearing. As a result, the usage of IoT will expand from use within a single office or site to use throughout the entire supply chain. IoT-based services and solutions operate on a platform that encompasses not only the entire corporate activity but also the entire value chain to promote overall rationalization. Next, Table 2 shows an example representation of the layer map, which is an artifact of Theme II.

The extraction of elements and mapping to the relevant hierarchy was carried out by the working group facilitators based on the keywords that each person extracted from the cases. The left column of Table 2 follows a logical hierarchical axis, but the detailed hierarchical items are set up by positioning the role of the infrastructure in this subcommittee with reference to the recent examples of smart city and super city hierarchies.

We used a simple linking-grid method to connect representative elements of each layer and found that the representative elements in layer IV including "cloud computing" and "platform" could be combined with the elements of "IoT", "AI", and "robotics" in layers V and VI and with "old infrastructure management" in layers II and III. This demonstrates that each element of "preventive maintenance" and "public-private partnership" was connected. In the future, this will be further developed into a detailed roadmapping activity.

Effect of Adding Knowledge Co-Creation to Roadmapping

The results of the analysis of the open-ended responses to the questionnaire are listed in Figure 3. The following words were extracted as conceptualized terms: "acquisition of knowledge", "difficulties specific to smart infrastructure", "in-depth research activities", and "difficulties in more in-depth research activities". For the extraction of the concept of "knowledge acquisition", representative text data are provided in Figure 3, including two for "difficulties specific to smart infrastructure", two for "in-depth research activities", and three for "difficulties in more in-depth research activities".

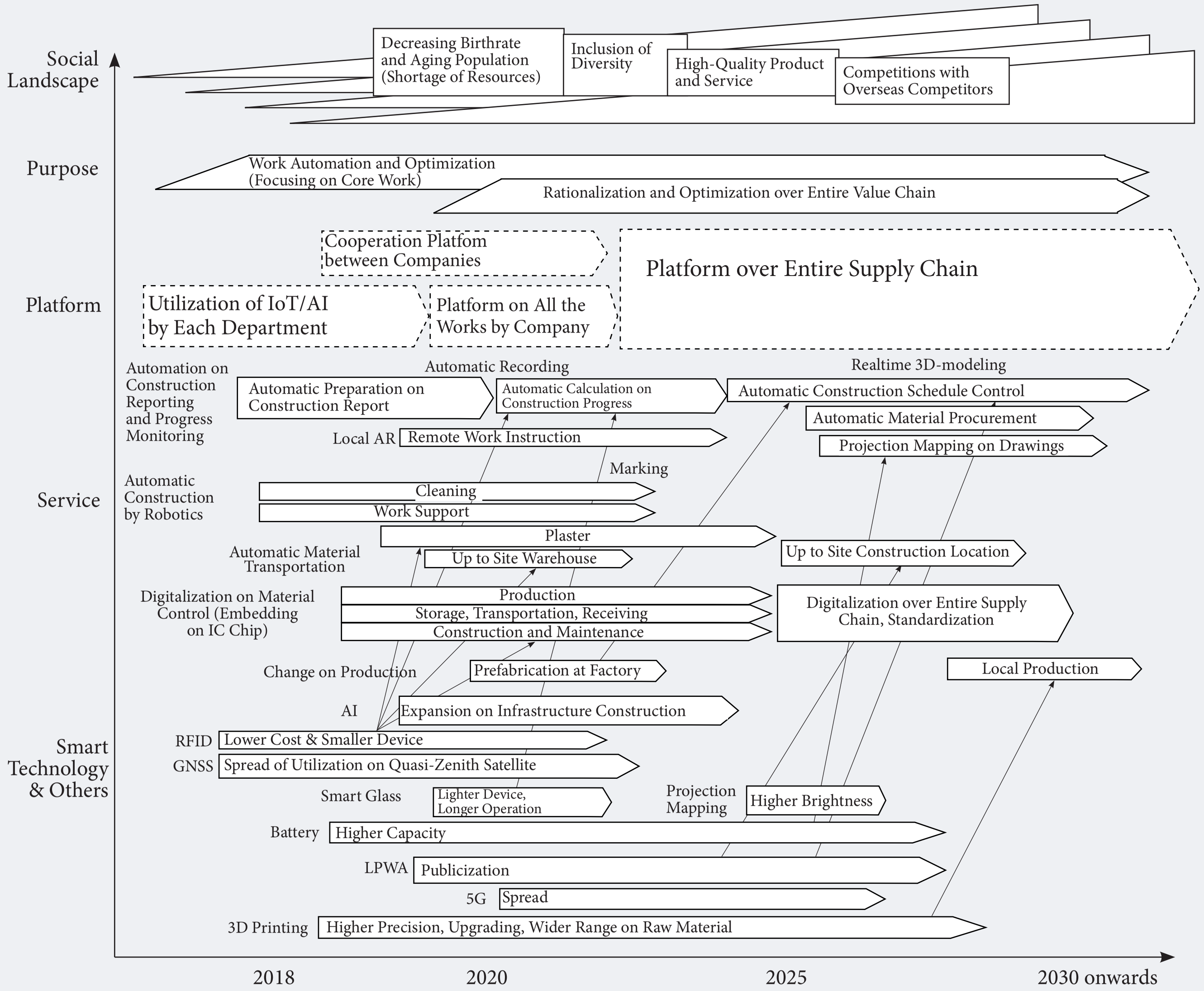
This was a meaningful and learning activity because we were able to acquire knowledge by using the research in the subcommittee and we were able to obtain a more concrete image by implementing a systematic expres-

Table 2. **Layer Map of Smart Infrastructure**

Layers	Short Term	Medium Term	Long Term
I. Social Issues, Vision, Policy	Decreasing Birthrate and Aging Population, Society 5.0, Industry 4.0, SDGs, Aging Infrastructure	Lack of Working Population, National Resilience, Monetization for Social & Regional Implementation	Super Aging Society, Export on Smart Infrastructure
II. Solution, Service	Watching Service for those Living Alone, Sharing of Seniors' Knowledge, Maintenance on Aged Infrastructure, Energy Saving & Renewable Energy Service	Smart House, Automated Checkout, Predictive Maintenance, Subscription Business Model	On-Demand Service (e.g., Transportation), Hydrogen Economy
III. Organization, Work/Business Procedure	Cooperation between Ministries, Collaboration between Public and Private Sectors, Concession Contract, Leadership of Local Chief Executive	Digitalization of Public Administrative Work, Integration between Layers	Revision of Rules, Mega City
IV. Data, Information, Software Infrastructure	Cloud, Platform for each Purpose, Voice Input	Advanced Analysis on Big Data, Remote Operation	Cooperation between Each Platform, Virtual Twin
V. Hardware (Physical) Infrastructure, ICT Hardware Infrastructure	Wireless LAN (located anywhere), Smart Meters (IoT Sensors)	5G Facility, Hardware Renovation	New Hardware (e.g., for Self-Driving)
VI. Smart Technology (Conventional ICT + Sensing/IoT/AI/RT)	5G, Non-Destructive Examination, Data Analysis Technology, IoT (Various Sensor Technology), Drones, VR/AR, Cyber Security	AI-API, Blockchain, Robotics (e.g., for Infrastructure Inspection)	SSPS (Space Solar Power System)

Source: authors.

Figure 2. **Detailed Roadmap on Infrastructure Construction**



Source: authors.

Figure 3. **Analysis of Open-Ended Responses to the Research Findings**

1st order analysis		2nd order analysis (conceptualized terms)
• Learn about the latest trends • Learn about advanced case studies • Get a more concrete picture • Learn about lectures and visits that we cannot hear about in our own company alone • Stimulation that we cannot get from our own company	→	Gaining knowledge
• The direction of the country, the challenges of the target municipality, and the project concept for what it should be • Horizontal integration of the whole plan is a major challenge	→	Difficulties specific to smart infrastructure
• It was difficult to find time to create and develop a vision • There was a lack of discussion on what it should be	→	In-depth research and investigation activities
• Research of various materials and online information before the pre-inspection visit • Future technology roadmapping • Ongoing research study activities	→	Difficulties in further in-depth research and investigation activities

Note: Only the conceptualized words and representative text data are shown.
Source: authors.

sion through the in-depth research activities. This led to a clarification of some of the difficulties inherent in the smart infrastructure. From this result, it can be confirmed that we resolved the behavioral and thinking characteristics peculiar to industrial businesspersons and engineers. We also acquired new knowledge through dialogues with those in charge of the site or experts (Figure 4). This would not be possible if one relied upon published literature alone. These results show that field research and expert lectures promoted the participants' understanding of the level of enthusiasm and the real issues and concerns of the people involved. However, when it came to the process of expression, the ability of each person was different, and the sharing and mastering of the process as a subcommittee was not yet attained. These results suggest that the high level of satisfaction in the knowledge co-creation roadmapping activities is mainly due to knowledge acquisition at the site and common experiences. In addition, we found that there is room for improvement in terms of the processes and tools with respect to knowledge mapping. From this result, it has been confirmed that focusing on (ii) acquiring knowledge is better in order to realize the effect of knowledge co-creation roadmapping in the early stage, even though mastering of this method is gradual.

Overall Evaluation of Knowledge Co-Creation Roadmapping Activities

From the descriptive statistics in Table 3, we summarize the results in terms of the process, tools, and results of the knowledge co-creation roadmapping activities. With regard to the process, the significance of the process was well appreciated, as the mean value of the (4-1) significance of this process was the highest among all variables. Satisfaction with the activity also had a high mean value in terms of the (2) process of research as individual satisfaction and (3-1) process as an objective assessment, which indicates that this process of knowledge co-creation roadmapping activity is effective. On the other hand, the mean values decreased as they moved from individual satisfaction to objective assessment, and the mean scores for the (3-4) initiative as an objective assessment also decreased, which suggests the participants recognized that further process improvement was necessary.

Figure 4. **Analysis of Open-Ended Responses to the Research Process.**

1st order analysis		2nd order analysis (conceptualized terms)
Seriousness and real concerns that can be confirmed by field research Insights that could not be learned from document research alone	→	The usefulness of visiting sites and attending expert lectures
Gradually shared and established among subcommittee members over three to four years Stimulated by research and working group members	→	Gradual mastery of the process
It was not even close to being able to express what we obtained in the form of knowledge Depends on the personal opinions of each person in charge	→	Inadequate representation

Source: authors.

Table 3. **Descriptive Statistics of Questionnaire Results**

No.	Variable	mean value	standard deviation	95% confidence interval		minimum value	maximum value
				lower limit	upper limit		
1	(1) Results of the research	4.247	0.738	3.896	4.598	2	5
2	(2) Process of the research	4.441	0.669	4.123	4.759	2	5
3	(3-1) Objective assessment: process	4.00	0.707	3.66	4.34	2	5
4	(3-2) Objective assessment: tool (esp. software)	4.29	0.588	4.01	4.57	3	5
5	(3-3) Objective assessment: results	3.961	0.848	3.56	4.36	1	5
6	(3-4) Objective assessment: initiative	4.147	0.821	3.76	4.54	3	5
7	(4-1) Methodology and effectiveness of roadmapping: significance of the process	4.53	0.514	4.29	4.77	4	5
8	(4-2) Methodology and effectiveness of roadmapping: effectiveness of the tools	4.382	0.652	4.072	4.692	3	5
9	(4-3) Methodology and effectiveness of roadmapping: acquisition of collective knowledge	4.029	0.674	3.709	4.35	3	5

Source: authors.

With regard to the tool, both the (4-2) effectiveness of the tool and (3-2) tool as an objective assessment had high mean values. However, the objective assessment showed a lower mean, which suggests that although the respondents rated the tool as effective, they perceived there was room for improvement in the application of the tool to their activities. Furthermore, since the mean value of the tool was lower than that of the process, we can conclude that improving the tool would be desirable.

With regard to the results, the (3-3) results as objective assessment had the lowest mean of all the variables, although the mean scores were high for both (1) results of the research and (4-3) acquisition of collective knowledge. The results as objective assessment had a similarly lower mean. There are various factors that might increase the mean values of the results, and we consider the improvement of processes and tools to be one of them.

Since the results of high mean values are obtained for most of the variables, it has been confirmed that knowledge co-creation roadmapping is very effective for organizations in the social infrastructure industry. In order to apply this method more effectively, we should improve the suggested points in the future.

Discussion

Academic Implications

The roadmap developed during the knowledge co-creation roadmapping activities, called Output 1: Roadmap for Social Infrastructure Construction in Terms of Labor Complementary Measures, showed that the low cost of devices, high battery capacity, and the elimination of communication constraints have led to increased servitization and individualized optimization (e.g., inter- and intra-site utilization within a single office or site). In this study, we found a directionality from the local optimum (e.g., single office or single construction site) to the global optimum (e.g., the entire supply chain). In Output 2: Roadmap for the Operation and Maintenance of Social Infrastructure, we found the potential for a smarter infrastructure based on the "cloud" and "platform" as software infrastructure. Previous roadmapping activities on social infrastructure [*Daim, Oliver,* 2008; *Lee et al.,* 2013] have primarily discussed the technology development process. The novelty of our work is that, through the process of (i) sharing thoughts and feelings and (ii) knowledge acquisition and common experiences in the field in this method, we shared the context of how the technology is used and how the social situations are affected. It suggests that the discussion on improving social issues as well as technological progress was effective.

From the questionnaire responses, we know that the majority of participants found the process of knowledge co-creation roadmapping to be significant and effective as a tool. Although past reports have demonstrated that there is a knowledge creation aspect to roadmapping activities [*Phaal et al.,* 2005], there has been no adequate research on whether such knowledge creation also takes place in practice in industry organizations that include competitors. While myopia of vision [*Smith et al.,* 2010] and knowledge sabotage awareness [*Serenko,* 2019] due to being in the same industry are likely to occur in future discussions, our method based on organizational knowledge creation activities [*Nonaka,* 1994] can effectively alleviate this risk. This means that our proposed roadmapping method, which also includes the acquisition of knowledge and common experience in the field, has proven to be an extremely effective foresight activity to consider long-term plans for developing together as an industry.

Furthermore, the open-ended responses demonstrate that satisfaction in the knowledge co-creation roadmapping activities was mainly due to knowledge acquisition on site and shared experiences. This points to the importance of common experiences as a means of acquiring knowledge together in a state of tacit knowledge, including true challenges and enthusiasm, and facilitating a more collaborative approach by (i) sharing thoughts and feelings. In knowledge creation for open organizations such as industry organizations, common experience is an effective means of overcoming impediments such as discussion divergence [*Chambers,* 2004] and achieving the efficient management of a well-directed meeting.

Practical Implications

We believe that knowledge co-creation roadmapping will work well for organizations with the same conditions as the social infrastructure industry organization. The industries are already matured and threatened by cutting-edge technology (e.g., digital technology) that differs from their accumulated industry-specific expertise and also they face challenges presented by new entrants on the market. However, in the case of the social infrastructure industry organization, it took three years to gradually master and share this method across several themes, and we think that the same is true for other industrial organizations. Therefore, from the viewpoint of practitioners in the social infrastructure industry, we propose practically useful ideas to apply this method to other industrial organizations. The first idea is to focus on sharing thoughts among members and acquiring knowledge that differs from their industry-specific expertise as the initial step in order to move toward sharing and establishing this method. The second idea is to reduce the negative effects on behavioral and thinking characteristics unique to industry individuals by engaging in dialogue with the person in charge of the site through site visits or the expert in the case of a lecture. The third idea is to request an expert on roadmapping to deliver a lecture in order to explain the basic knowledge and procedure, instead of starting roadmapping by themselves.

Regarding bias to utilize our method, we think that the behavioral and thinking characteristics of industrial businesspersons and engineers can become a bias. In the case of the social infrastructure industry, we found that the participants tended to come up ideas in a field-oriented or an actual object-oriented concrete manner based on their own experiences, rather than meta thinking. Based on the result of the open-ended questionnaire survey, we believe that the bias due to the behavioral and thinking characteristics could be resolved by applying knowledge co-creation roadmapping. Therefore, the way to reduce bias includes engagement in dialogue with the concerned persons through site visits or with expert lectures

Conclusion

With the development of the smart urban concept, infrastructure companies engaged in general construction and plant construction need to envision the future as an industry and make decisions on the basis of their collective positioning rather than exploring future trends and making policies individually. In this context, we used the case study of an industry organization (the Engineering Advancement Association of Japan, which is made up of multiple infrastructure companies) to investigate how roadmapping can promote collective knowledge creation and enable the participants to find a possible vision of the future.

As members of this collaborative research group, we conducted two types of roadmapping activities to gain insight into the prospects for a smarter infrastructure. The members shared a framework for smart infrastructure and were able to visualize the role of smart infrastructure through a new hierarchical design and time-series analysis, resulting in a unique outcome that reflects the characteristics of the infrastructure business, which is different from the IT business. The results of this study can contribute to providing a knowledge base for businesspersons and engineers concerned with the maintenance and design of smart cities and regional infrastructure.

With the common sense of limitations of development that each company in the industry possesses, an open industry organization consisting of members sent by individual companies could also carry out roadmapping activities based on the model of organizational knowledge creation [*Nonaka,* 1994]. In particular, we found that the process of acquiring new tacit knowledge through the common experience of visiting sites and listening to lectures by experts and turning it into collective knowledge by reviewing them among the members, functioned well due to the characteristics of each member. However, to efficiently systematize the findings and utilize the framework (i.e., the roadmap), we need to develop a simpler implementation tool that can enhance the sharing among the members. This will be the focus of our future work.

Knowledge co-creation roadmapping is a method for industry organizations to develop a future-oriented plan. This method is effective in finding solutions for social issues that cannot be dealt with only by industry-specific expertise. The findings of our study indicate that the procedure is effective in situations where multiple actors need to plan for future issues in a coordinated manner. Therefore, our method will contribute to the planning for a smart city and the consideration of environmental sustainability, because those issues need collaborative actions among multiple stakeholders. As future research, we added the need for study of whether or not this method is also available in other industries.

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Agile Roadmapping: An Adaptive Approach to Technology Foresight

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Abstract

Technology roadmapping has become an important foresight tool for science, technology, and innovation (STI) policy and technology strategy development. There are, however, challenges in translating evidence from foresight into the strategies of STI agencies and the planning of research & technology development (RTD) organizations. While the foresight evaluation literature identifies methodological issues related to evidence granularity, scope, and stakeholder confidence, there is limited guidance on how to ensure roadmapping outputs are strategically relevant, appropriately detailed, and credible. This paper highlights the potential of using structured visual roadmapping frameworks to anticipate potential strategic foresight evidence failures and using the adaptive and iterative nature of roadmapping processes to address them. In this paper, we distinguish between: the roadmapping framework 'canvas'; the foresight evidence captured on the canvas; the process of generating the evidence; and any final strategic plan developed using that evidence (with goals, milestones, actions, etc). We investigate efforts to use the roadmapping canvas as a research tool and diagnostic to explore emerging technology trajectories and innovation 'pathways'. We demonstrate that key patterns of evidence distribution on the roadmapping canvas have the potential to reveal where further evidence may need to be gathered, or where further triangulation of stakeholder perspectives may be required. We argue that by adaptively addressing these patterns at key stages within the roadmapping process (and appropriately re-scoping, re-prioritizing, and re-focusing foresight effort and resources), the granularity, coverage, and consensus of the roadmapping evidence can be greatly enhanced. We conclude the paper by summarizing a set of novel principles for adaptive agile roadmapping, reflecting on the implications for foresight more generally, and outlining a future research agenda to test and refine this approach to agile foresight.

Keywords: technology roadmapping, foresight methodology, emerging technology strategy, STI policy

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Technology roadmapping has become an important foresight tool for science, technology, and innovation (STI) policy and government R&D strategy. There are, however, challenges in translating evidence from foresight into the strategies of STI agencies and research & technology development (RTD) organizations. In this paper, we explore the opportunities to take advantage of the distinctive properties of technology roadmapping (frameworks and processes) to navigate the complexity of innovation system- or industry-level foresight and to enhance the relevance, granularity, and credibility of strategic foresight evidence.

Although the origins of roadmapping lie in firm-level strategy development [*Kerr, Phaal,* 2020], technology roadmapping has become an important foresight tool for STI policy [*Cho et al.,* 2016], where it is used, for example, to analyze technology innovation dynamics as part of public-private industrial sector-level strategic planning [*Baldi,* 1996; *Harrell et al.,* 1996; *Nimmo,* 2013] or national technology foresight [*de Almeida et al.,* 2015; *Hussain et al.,* 2017; *Saritas, Oner,* 2004]. There are, however, variations in emphasis (and challenges) when applying the approach at the innovation system or industrial levels. In contrast to firm-level technology roadmapping, innovation system-level exercises may involve even more complex analyses (with a more diverse set of stakeholders), more complex and longer term innovation system dynamics, and broader socio-political trends and drivers [*Cho et al.,* 2016; *Isenmann,* 2008; *Schuh et al.,* 2013]. Furthermore, unlike firm-level roadmaps, where the stakeholders commissioning the roadmap are often the same ones that will use the outputs, government-commissioned foresight exercises are often intended to generate an evidence base to be used by a range of different public sector actors (e.g., research and innovation agencies, research and technology organizations) for their individual strategic purposes [*Cho et al.,* 2016; *Schuh et al.,* 2013]. In this context, the general challenge of ensuring outputs have the right level of detail, scope, and stakeholder confidence [*Lee et al.,* 2012; *Schuh et al.,* 2013] to support the strategy development needs of the foresight evidence users can become more difficult.

Despite the increasing popularity of innovation system-level foresight, however, there is limited guidance for ensuring the effectiveness and impact of STI roadmapping exercises [*Kostoff, Schaller,* 2001; *Oliveira, Fleury,* 2015]. Similarly, there is little guidance on characterizing or reporting on the limitations of a roadmapping evidence. Indeed, STI roadmaps rarely contain statements on any limitations of the underpinning data or analysis, from which the academic or practitioner foresight communities might learn.

This paper sets out to address this issue by reviewing the foresight evaluation literature and broader technology roadmapping literature for insights and approaches to identifying and addressing the limitations of foresight evidence and potential sources of error. We then translate these insights into the visual language of roadmapping and explore the relationships with particular patterns of foresight evidence distribution on the roadmapping canvas. In particular, we demonstrate that unique qualities of roadmapping as a foresight tool – the structured visual representation of evidence, the attention to innovation pathways, and the scalable/systemic nature of the framework – mean that key patterns of data distribution on the roadmapping canvas can help anticipate potential sources of foresight evidence failure. Furthermore, we argue that by adaptively addressing these patterns at key stages within the roadmapping process – and, where appropriate, re-scoping, re-prioritizing, and re-focusing the roadmapping effort and resources – the granularity, coverage, and consensus of the roadmapping evidence should be greatly enhanced.

The Challenges of Translating (Innovation System-Level) Foresight and Technology Roadmapping Evidence

In this section, we explore the challenges of technology foresight at the innovation system- or industry-level. In particular, we examine the difficulties of ensuring foresight outputs are accepted *and used* by STI stakeholders as part of the development of research & innovation strategies. In this context, we review what the foresight and technology roadmapping literature tells us about sources of error, evidence limitations, and barriers to outputs being used. We also review literature related to the evaluation of foresight studies and roadmaps, including any guidance or principles on how to improve roadmapping processes and performance.

In contrast to firm-level technology roadmapping, industry sector-level or innovation system-level studies typically involve more complex analyses, reflecting the system complexity of the innovation dynamics being studied. Consequently, such studies involve greater effort and resources. As Cho et al point out: *"With respect to procedures, scope, resources, and time spending, industry roadmap requires much more than the corporate one. While corporate roadmaps target a particular technology and product, industrial roadmaps sometimes deal with wider R&D issues associated with a high level of emerging technology and product trends in the industry"* [*Cho et al.,* 2016]

In common with the general characteristics of foresight studies, roadmapping analyses supporting innovation strategies are intrinsically *"complex, uncertain and conflicting"* in nature [*Saritas, Oner,* 2004]. Foresight analyses of emerging technologies (and associated challenges and opportunities) are increasingly multidisciplinary, requiring input from a multiplicity of experts and stakeholders, from a range of disciplines and organizations, all with potentially different perspectives. Furthermore, these actors will have a range of different interests, values, incentives and, consequently, different priorities [*Saritas, Oner,* 2004].

This complexity has further consequences for the effective commissioning and designing of foresight analyses. Policymakers commissioning technology roadmaps (or other foresight analyses) may not anticipate or understand the scale of system complexity, the diversity of stakeholder perspectives, or the interdependence of innovation activities, events and policies [*Saritas, Oner,* 2004].

There are a range of challenges in developing and applying STI policy evidence generated from foresight [*Georghiou, Keenan,* 2006; *Martin, Irvine,* 1990; *Saritas, Oner,* 2004]. Alongside issues related to organizational absorptive capacity and alignment with policy life cycles, there are also important methodological issues - related to the precision, relevance, and credibility of foresight evidence – which can inhibit its translation into STI strategy development. It is these challenges – and approaches to overcoming them – that are the main focus of this paper.

As pointed out by Georghiou and Keenan, *"Foresight is not always tuned to the needs of recipients and hence, to extend the analogy, the signal may be obscured by noise and not picked up. Information needs to be presented in such a way that policy/strategy mechanisms can receive and absorb it."* [*Georghiou, Keenan,* 2006]. This is an issue facing policy makers, R&D

agency officials, and also public-private research & technology development (RTD) organizations [*Salmenkaita, Salo,* 2004].

Many foresight exercises often fail to reliably generate evidence in a format that can be effectively used by policymakers or that is sufficiently focused on 'specific [policy] questions' [*Day,* 2013; *Kunseler et al.,* 2015].

One of the primary reasons for the lack of impact of foresight analysis is *"the treatment of foresight and its implementation as separate processes without serious attempts to build bridges between or to link the two"* [*Georghiou, Keenan,* 2006]. The analysis of UK foresight highlights deficiencies in *"establishing the link between requirements and eventual implementation and starting initiatives, [as] major problems that the UK foresight studies experienced"* [*Saritas, Oner,* 2004].

Foresight exercises intended to inform strategy development for emerging technology research and innovation investment require evidence on the innovation pathways of emerging technologies (between research and eventual applications). These pathways *"are many, not necessarily linear and require an enormous amount of data for any attempt to link research with application. Substantial time and effort are required to portray these links as accurately as possible, and substantial thought is necessary to articulate and portray the massive amount of data in a form comprehensible to potential investors"* [*Saritas, Oner,* 2004].

Given this complexity, it is not possible at the commissioning stage of a foresight exercise to fully anticipate how complex the innovation dynamics of a particular technology might be. One cannot, *ab initio,* know what level of microtechnical innovation detail may be required in order to identify potential technology 'innovation pathways'. One cannot precisely anticipate the level of consensus or disagreement among innovation stakeholders (regarding key events, trends, barriers, priorities, etc). In terms of foresight process, therefore, it is not possible to fully identify the right cohort of foresight exercise participants (in terms of the sampling of stakeholder perspectives and expertise) or strike the right balance of exercise scope and resources (in order to ensure the outputs are sufficiently granular, focused, and credible to be actionable). This suggests that the strategic foresight analysis of highly complex technology innovation systems must be both adaptive and iterative, to ensure outputs that are relevant, usable, and trusted by 'users'.

This poses important methodological questions about how to both configure technology foresight exercises with strategic evidence requirements of the STI policy users in mind; and how to effectively monitor and regulate the collection of strategic foresight evidence to ensure these requirements are met.

In the following section we explore how technology roadmapping analysis and process frameworks offer the potential to:

- facilitate the configuration of foresight exercises to address users' strategic evidence requirements;
- reveal when evidence gathered on particular innovation activities or dynamics may require more granular detail, stakeholder input, or focus on particular innovation system elements or phases;
- offer structured decision points within the foresight exercise for adaptation in response to emerging findings – opportunities for re-scoping, re-prioritizing, and re-focusing foresight effort and resources.

The Technology Roadmapping Canvas: A Diagnostic Tool for Exploring Innovation System Dynamics

In this section, we review the use of technology roadmapping as a foresight and strategy tool – highlighting its distinctive features and functions (in comparison with other foresight tools). We also explore the application of the roadmapping frameworks as a research tool, in particular its use in structuring analyses of emerging technology innovation dynamics and sociotechnical change. In this context, we explore how certain features of the roadmapping canvas may offer the potential for its application as a diagnostic tool to examine the sufficiency, efficacy, and credibility of foresight evidence.

Comparison of Roadmapping and (Other) Foresight Methods

Technology roadmapping is one of a large number of foresight-related methods.[1] Following Park et al. we will define roadmapping 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].

As with national level foresight, roadmapping exercises typically convene *"people representing different expertise and interests, and use instruments and procedures that allow participants to simultaneously adopt a micro view of their own disciplines and a systems view of overriding or shared objectives"* [*Coates et al.,* 2001].

Roadmapping often integrates outputs and insights from other foresight analyses to provide evidence for strategy development and planning *"as a tool, defining paths to meet future requirements, roadmaps can assist to connect the future's requirements and today's research areas"* [*Saritas, Oner,* 2004]. As highlighted by Popper, *"the bridge between foresight and planning is sometimes achieved with methods like roadmapping"* [*Popper,* 2008].

Because of its role in supporting strategy development, roadmapping is often considered a 'downstream' foresight tool (by contrast with more exploratory methods such as horizon scanning). Although the final output of roadmapping analyses may identify key planning milestones and options for strategic goals, the roadmapping process typically contains an opportunity-scanning phase. Roadmapping can, therefore, be both exploratory and normative, capturing both types of evidence within a single integrating system framework) [*Barker, Smith,* 1995; *Cho et al.,* 2016; *Kappel,* 2001].

More generally, roadmapping analyses can address a range of key foresight success factors, for example: *"Be flexible, capable of generating options and alternatives; effectively integrate technology push with business pull; address in a co-ordinated manner the whole range of activities from the holistic strategic level down to relatively small details; directly address the need to secure buy-in and involvement at all levels, with commitment to implement the outcomes"* [*Barker, Smith,* 1995].

Roadmapping has particular strengths, of especial relevance in the context of this paper, including its potential to *help navigate the "the multidimensional characteristics and complex nature of foresight studies"* [*Saritas, Oner,* 2004]. In particular, roadmapping has the ability *"to capture, manipulate and*

[1] Including Delphi, bibliometrics, stakeholder mapping, scenario planning, horizon scanning, expert panels, SWOT, citizen panels, etc. [*Popper*, 2008].

manage information to decrease complexity in the foresight by constructing roadmaps" [*Saritas, Oner,* 2004].

Because of the firm-level origins of technology roadmapping, the approach puts an *"emphasis on visual, easy-to-comprehend descriptions of customer needs, technology responses, and R&D programmes offers several benefits"* [*Barker, Smith,* 1995]. Roadmapping has, therefore, qualities that lend themselves to generating evidence that is strategically relevant and usable by R&D organizations. As highlighted in the context of firm-level roadmapping, the technique can effectively *"facilitate communication at the operational commercial and technical level, and with senior management too, as well as providing a practical means for ensuring R&D programmes are apposite, correctly prioritized, and adequately resourced."* [*Barker, Smith,* 1995].

Roadmapping's visual approach and systems perspective has a number of advantages. *"The value of the graphical models is that they show R&D projects and requirements in context rather than in isolation, they can depict new perspectives rapidly and they can serve as a focal point for enhanced communications and more detailed total systems analyses"* [*Saritas, Oner,* 2004]. Roadmapping's effectiveness at systems analyses is further enhanced by its ability to operate at a wide range of system levels (from company division level to firm-level to global industry-level) and address a range of innovation system phenomena (from market trends to emerging scientific R&D domains) [*Kappel,* 2001; *Phaal, Muller,* 2009]. This scalability and adaptability offers the potential to readily respond to the need for evidence in greater sub-system detail.

The Roadmapping Framework

In this section we explore key features of the architecture of the roadmapping framework. We review efforts to use the roadmapping framework canvas as a research tool to study emerging technology innovation dynamics and sociotechnical change. We conclude by summarizing the distinctive features of the roadmapping canvas which offer the potential for its application as a diagnostic tool to monitor and regulate the sufficiency, efficacy, and credibility of strategic foresight evidence as it is gathered.

To understand the distinctive features of technology roadmapping – and their potential to support the generation of foresight outputs that meet STI policy users' strategic evidence requirements – it is important to distinguish between the roadmapping framework, roadmap content, and roadmapping process (Table 1).

Phaal and Muller highlight the importance of distinguishing between the roadmapping framework (canvas) and the content (information, stakeholder perspectives, insights, etc) captured and organized within the framework [*Phaal, Muller,* 2009]:

1. *An underlying information-based structure (the roadmap architecture) — how the information contained within the roadmap is organized, which represents the key elements of the system (layers and sub-layers of the roadmap), set against time.*
2. *An overlaying graphical layer, with format, style, and color chosen to represent the roadmap structure and its content for communication purposes. The multi-layered time-based format is posited as the most comprehensive and flexible format for developing roadmaps, although different graphical styles have been developed for summary and communication purposes."*

These graphical roadmapping frameworks [*Park et al.,* 2020; *Phaal et al.,* 2004b] can be considered dynamic systems frameworks, with the architecture of the roadmap providing a coherent and holistic structure (and common language) within which the innovation pathways and the evolution of the system and its components can be explored, mapped and communicated [*Phaal, Muller,* 2009).

In its most generic form, the visual roadmap is a time-based chart, comprising a number of layers, corresponding to a range of different innovation activities, typically including commercial and R&D perspectives (Figure 1). The roadmap enables the evolution of markets, products (and services), and the innovation pathways of technologies to be explored, together with the linkages, interdependencies, and discontinuities between the various perspectives. The roadmapping approach draws together key concepts from the technology strategy and transitions literature, by the use of its layered innovation activity structure set against the time dimension [*Phaal et al.,* 2004a].

Within the generic roadmap canvas, three broad layers are set horizontally across the two-dimensional space of the canvas with a horizontal time axis [*Phaal et al.,* 2004b; *Phaal, Muller,* 2009], corresponding to:

- A top 'purpose' layer, capturing 'know-why' innovation information: This layer captures evidence and insights related to trends and drivers that govern the overall goals or purpose associated with the roadmapping activity.
- A middle 'delivery' layer, capturing 'know-what' information: This layer captures evidence relating to the tangible systems that need to be developed to address strategic opportunities and challenges, and respond to trends and drivers (captured in the top layer). In firm-level roadmaps, this typically corresponds directly to the evolution of products in terms of their functions, features, and performance. In innovation system-level roadmaps, this often corresponds to the functions, features, and performance of technology platforms (upon which private sector applications, products, and services are based).
- A bottom 'resources' layer, capturing 'know-how' information: This layer captures evidence related to the resources that need to be marshalled to develop the required products, services and systems, including knowledge-based resources, such as technology, skills, and competences, but also other resources such as finance, partnerships, and facilities.

The process by which this evidence is gathered, integrated, and synthesized is outlined in the following section.

The Roadmapping Process: Phases and Activities

The accumulation of foresight evidence within the roadmapping canvas typically happens within a sequence of steps or phases. The transitions from one stage to the next offer opportunities to reflect on the data gathered, the emerging patterns, and evidence gaps. In particular, these are opportunities to adapt the focus and granularity of analyses, reallocate resources and effort, and introduce new stakeholder perspectives and expertise, as appropriate.

Depending on the scope and ambition of the exercise, the stages of a roadmapping study can take place within a single event involving a single group of stakeholders or can be part of a staggered set of exercises, integrating information from other analyses, and inviting participants with different perspectives and expertise at different stages. The sequencing of able 1. **Roadmapping Dimensions**

Item	Description
Framework	Dimensions, elements, organizing principles and graphical canvas within which evidence and strategic information is gathered
Content	The evidence - data, insights, perspectives, and so on, as well as strategic priorities, milestone, and goals, which are collected and organized within the framework
Process	The stages, activities and sequencing of actions related to collecting and organizing foresight evidence and strategic/planning information
Source: authors.	

evidence-gathering phases – from more exploratory analysis (of trends and drivers, opportunities and challenges) to increasingly more strategically-focused considerations – is discussed in more detail below.

While there are a range of different approaches to defining and organizing the different phases and activities of a roadmapping process [*Bray, Garcia,* 1997; *Nimmo,* 2013; *Phaal et al.,* 2007; *Yasunaga et al.,* 2009], most approaches involve some version of the following: establishing a vision; exploring the landscape of capabilities and opportunities; and revealing innovation pathway options. In practice, these steps are often preceded by a preliminary planning phase - clarifying roadmap aims and are followed by implementation and evaluation phases: translating and implementing outputs; validating and re-visiting the roadmap (Table 2).

This phased approach to gathering, integrating, and synthesizing foresight evidence is an important aspect of what makes the roadmapping process so adaptable – offering opportunities to reconfigure foresight efforts and resources to ensure the outputs are as useful and credible as possible.

Distinctive Features of Roadmapping (Supporting Evidence Diagnostics)

In this section, we highlight key aspects of roadmapping which support its functionality as an evidence diagnostic tool – allowing the managers of foresight exercises to examine whether the evidence and insights gathered have sufficient granularity, relevant innovation focus, and stakeholder credibility. In particular, we review roadmapping's visual, integrating, scalable, iterative, and systemic nature and reflect upon the implications for the monitoring and regulation of foresight evidence collection.

The Visual Nature of Roadmapping

The graphical technology roadmapping canvas is designed to reveal patterns in evidence related to the complex innovation system dynamics of emerging technologies. In particular, the visual nature of the roadmapping approach means that the roadmapping-based tool can more effectively reveal temporal relationships between key events in different innovation activity domains [*Park et al.,* 2020]. Saritas and Oner characterize the roadmapping methodology in terms of its ability to *"capture, visualize, manipulate and manage information to decrease complexity in foresight"* [*Saritas, Oner,* 2004].

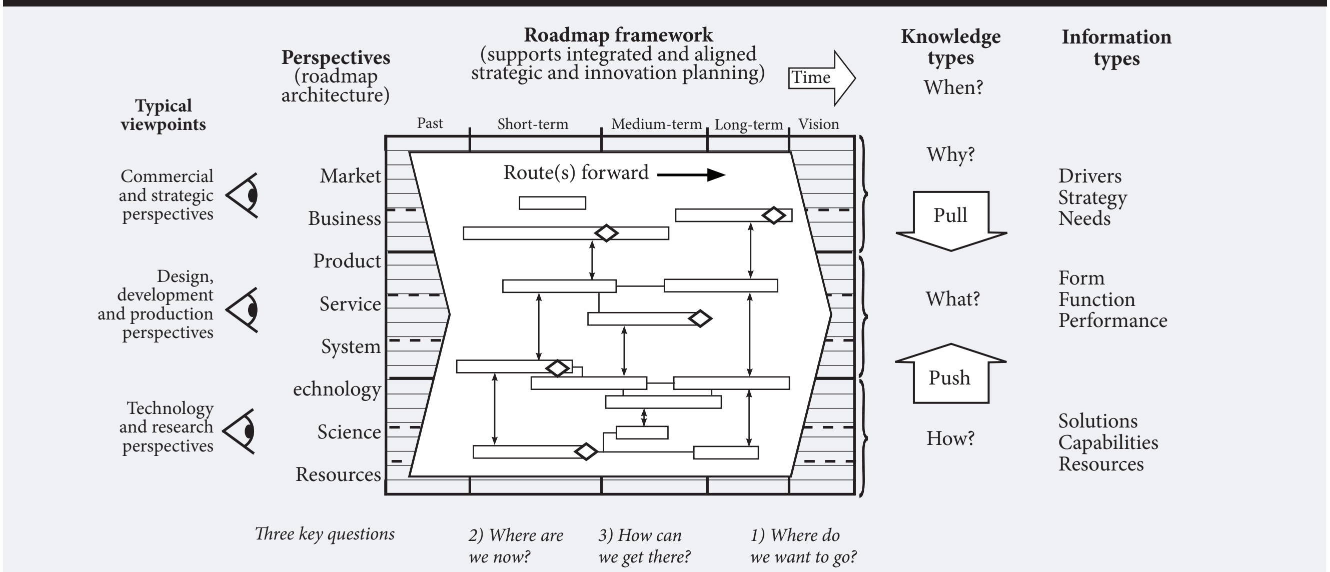
Roadmapping's visual representation of *"customer needs, technology responses, and R&D programmes"* supports dialogue and communication between stakeholders from different operational, commercial, and technical perspectives, but also supports implementation, offering *"a practical means for ensuring R&D programmes are apposite, correctly prioritized, and adequately resourced"* [*Barker, Smith,* 1995].

The visual nature of the roadmapping framework not only helps reveal patterns in evidence, but also potential gaps in evidence, the paucity of detail in particular areas of the innovation canvas, and unexplained linkages or correlations deserving further attention. These opportunities to monitor and regulate evidence gathering, based on observed patterns, is discussed in more detail below.

The Integrating Nature of Roadmapping

The roadmapping framework is designed to gather and integrate evidence and insights from a range of innovation system stakeholder perspectives related to system activities, linkages, and elements, at different stages of innovation lifecycles. Furthermore, the canvas can be used to capture exploratory evidence (scanning future trends, opportunities, challenges),

Figure 1. **Basic Multi-Layered Roadmapping Architecture**



Source: [*Phaal, Muller,* 2009].

Table 2. **Roadmapping Stages**

Stage	Contents
Clarifying roadmap aims	Articulating and specifying the roadmapping exercise's focus and scope as well as intended outputs and impact
Establishing a vision	Scanning trends, opportunities/challenges and establishing a consensus vision among participants
Exploring the landscape of capabilities and opportunities	Surveying current (and potential) capabilities and opportunities; evaluating the relevance of particular capabilities to address opportunities; identifying innovation barriers and requirement gaps; and prioritizing innovation opportunity destinations
Revealing innovation pathway options	Investigating strategic innovation pathway options – navigating innovation barriers, filling requirements gaps, leveraging enabling factors, and identifying potential intermediate goals and milestones
Translating and implementing outputs	Translating roadmapping outputs into the strategic planning exercises of stakeholder groups and organizations (including informing technology selection and investment processes)
Validating and re-visiting the roadmap	Following up with exercises to critique and validate elements of the roadmap, updating trend data and stakeholder insights, revising strategic goals and milestones

Source: authors.

normative forecasting evidence (focusing on desired future innovation system states), as well as strategic information (potential planning milestones and strategic goals) – all within a single integrating system framework. While the roadmapping framework is often used to gather input from stakeholders within facilitated workshops, the roadmap canvas can also be (pre-) populated with data and insights gathered from other foresight and strategy development processes[2] [*Hussain et al.*, 2017; *Kanama et al.*, 2008; *Oliveira, Fleury,* 2015; *Saritas, Oner,* 2004; *Strauss, Radnor,* 2004; *Vishnevskiy et al.*, 2015].

The juxtaposition on a single integrating canvas of evidence from different sources, system levels, and expertise facilitates efforts to reveal mismatches in stakeholder perspectives and potential gaps in evidence and sampling.

The Scalable Nature of Roadmapping

Not only can individual roadmapping exercises be carried out over a range of different scales and time periods but, in principle, the adaptive nature of roadmapping allows analyses which 'zoom in' and 'zoom out' to explore micro- or macro-system dynamics which are deemed important by roadmapping participants. Roadmapping can operate at different system levels, with most roadmaps positioned at either the industry-level (or innovation system level) or firm-level, with some variations in emphases [*Kappel,* 2001] in terms of focusing on sector trends and market failures (roles for government) to intra-firm coordination issues and product market opportunities. As highlighted by Phaal and Muller:

"*Roadmaps can cover a tremendous 'dynamic range', in terms of scale and complexity of the system. For example… a sector roadmap can be viewed at the level of a limited set of sector trends (order of magnitude* 10^1*)… or a complex system (within a sector) determined by millions of details (order of magnitude* 10^7*)… The scientific foundation of the technologies used in the systems may be orders of magnitude more detailed again. Nevertheless, the purpose of a roadmap is often to align scientific efforts with the sector trends. Roadmaps provide a means for addressing this complexity.*" [*Phaal, Muller,* 2009].

As discussed above, however, roadmapping has the potential to zoom in/out to investigate particular innovation activities/dynamics within a roadmap. The architecture of the roadmapping framework can be "*configured to suit the focus and scope of the issue being addressed*" [*Phaal, Muller,* 2009]. The scalability of roadmapping – its potential to "'*magnify' and focus on the issues and areas of the system of most importance*" – facilitates efforts to reveal inadequacies in the granularity of evidence being gathered or the focus on key innovation subsystems.

The Iterative Nature of Roadmapping

As discussed above, the different stages within the roadmapping process offer opportunities to reflect on the data gathered, on the emerging data patterns and evidence gaps. In particular, these offer opportunities to adapt the focus and granularity of analyses, reallocate resources and effort, and introduce new stakeholder perspectives and expertise, as appropriate.

A particularly important aspect of the iterative nature of roadmapping is the opportunity to engage new participants with important perspectives and expertise. As pointed out by Phaal and Muller, the roadmapping process "*is somewhat paradoxical in that the appropriate expertise must be employed to develop a roadmap, but the appropriate expertise becomes fully known only after a complete roadmap has been constructed. An iterative roadmap development process is, therefore, essential*" [*Phaal, Muller,* 2009]. In practice, therefore, many roadmaps are created in multiple iterations. A first iteration is often done in a short time-span, typically in one day (or a small number of days), often within a single workshop. Subsequent iterations may require more time - from a few days to a few weeks or months – depending on the complexity of the system being studied and one's ability to access relevant expertise as well as other contextual factors. These iterations ensure feedback between key perspectives (e.g. related to market trends and business opportunities; product, production, and operational requirements; technology and research capabilities). These iterations take place within an overall process of increasing focus during the roadmap creation, as participants converge on key elements of the roadmap based on the evidence gathered. Each iteration progresses through the same four phases of ideation, divergence, convergence, and synthesis [*Phaal, Muller,* 2009].

The ways in which the iterative nature of roadmapping might be used to more systematically identify opportunities to adapt the focus and granularity of analyses, reallocate resources and effort, and introduce new stakeholder perspectives and expertise, will be explored in more detail below.

[2] e.g., SWOT, scenario planning, horizon scanning, Delphi.

The Systemic (and Multi-Perspective/Multi-Disciplinary) Nature of Roadmapping

Technology roadmapping frameworks are structured to explore different perspectives on a particular technology innovation journey from different parts of the innovation system: technology and research; design, development, and production; commercial and strategic [*Phaal et al.,* 2004a; *Phaal, Muller,* 2009]. Furthermore, as highlighted by Saritas and Oner: "*Today, most of the problems cannot be analyzed by a single discipline. All complex problems—especially social ones—involve a multiplicity of actors, various scientific/technical disciplines, various organizations and diverse individuals. In principle, each sees a problem differently and thus generates a distinct perspective on it.*" [*Saritas, Oner,* 2004]. As with foresight more generally [*Georghiou, Keenan,* 2006], an effective roadmapping exercise requires ensuring the involvement of a broad *"range of actors engaged in science and innovation policy"*.

From a practical perspective, advice on roadmapping processes often highlights the "*importance of a suitable starting set of participating stakeholders*" involving a breadth of innovation system perspectives in terms of "*including technological + economic social or political aspects*" [*Schuh et al.,* 2013]. Similarly, guidance on roadmapping highlights the need to avoid "*being isolated*" pointing out that *"roadmap building projects usually depend on a high degree of interdisciplinarity"*, and the importance of avoiding a "lack of coherence", emphasizing the importance of relating "*issues of major interests (e.g. technologies) to other issues relevant in that context (e.g. products, applications and/or developments in the political, economic, social environment)*" [*Isenmann,* 2008]. Examples of high-profile roadmaps, e.g., the US Department of Energy roadmaps related to the building and construction sector, highlight the importance of involving stakeholders from across the innovation system – "*participants representing all phases of building process/stakeholders (manufacturers, developers, contractors, owners, architects, engineers…)*".

A key aspect of the systemic nature of roadmapping is its focus on exploring potential innovation pathways (and path dependencies) within the innovation system. High profile NASA technology roadmaps are defined in terms of their exploration of *"needed technology candidates and development pathways"* [NRC, 2012]. The ability of roadmaps to offer evidence related to potential innovation pathways is critical to their appeal as a foresight tool that can inform strategy and planning. As highlighted by Saritas and Oner, however, "*the pathways between research and eventual applications ('practical use' and 'widespread use' in UK foresight) are many, not necessarily linear and require an enormous amount of data for any attempt to link research with application. Substantial time and effort are required to portray these links as accurately as possible*" [*Saritas, Oner,* 2004].

The ways in which the innovation system framing of the roadmapping canvas - and the focus on generating evidence on potential innovation pathways - could be used to ensure the relevance of outputs for roadmap users, in particular for STI strategy development and planning, will be explored in more detail below.

Lessons from Roadmapping as a Research Tool: Exploring Technology Innovation Pathways and Socio-Technical Transitions

As well as a practical foresight tool, the roadmapping canvas can also be configured as a research tool and used to capture key innovation events and activities within studies of technological change, retrospectively and longitudinally [*Phaal et al.,* 2007]. In particular, in this context, the roadmapping canvas has demonstrated its potential to distinguish, display, and scrutinize different categories and sources of empirical data. In this section, we briefly review some of the theoretical foundations and recent experiments in using roadmapping as a tool for studying technological change, and reflect on the implications for roadmapping practice and opportunities to enhance the relevance, granularity, and credibility of strategic evidence outputs.

In recent years, a number of researchers have used the roadmapping framework as an instrument to study emerging technology innovation trajectories and socio-technical transitions [*Featherston et al.,* 2016; *Featherston, O'Sullivan,* 2017; *Ho, O'Sullivan,* 2019]. In particular, the roadmapping framework allows researchers to gather evidence in a structured way that follows an innovation system logic, helping to reveal linkages between key innovation system elements, actors, and activities (functions). In this context, the researchers have taken advantage of the correspondence between roadmapping dimensional layers and innovation system functions [*Hirose et al.,* 2015; *Ho, O'Sullivan,* 2019; *Park et al.,* 2020].

These research studies involved gathering and representing a variety of categories of evidence about key innovation events and activities influencing emerging technological innovation trajectories within the roadmapping framework. Rather than using workshops, the researchers collected information and insights from a variety of sources: semi-structured interviews, reviews of literature from technology and industry studies, standard databases, market analyst reports, and reviews of 'grey' literature (e.g., studies by government agencies or national academies, many of which draw upon an analysis of patent databases, bibliometrics, etc) [*Park et al.,* 2020].

In methodological terms, it is worth noting that the use of the roadmapping framework as a research tool has some correspondence with other approaches to studying technological change. For example, Van de Ven's [*Van de Ven,* 1993] use of a framework of 'event tracks' to study the emergence of industrial infrastructure that facilitates the transformation of scientific knowledge into technology-based products or services. These tracks are analogous to key categories of roadmapping layers and are used to explore how events and activities related to distinct categories of infrastructure (e.g., different institutional arrangements, resource endowments, and proprietary activities) co-evolve with technological innovation [*Park et al.,* 2020]. The roadmapping framework also has some correspondence with the 'Multi-Level Perspective' framework deployed by, for example, for qualitative longitudinal case studies of technological emergence [*Geels,* 2002]. It allows for the systematic tracking of key transitions from niche to regime, paying attention to dimensions influencing technological transitions (e.g. sectoral policy, infrastructure, user practices, techno-scientific knowledge) [*Park et al.,* 2020]. In this context, the research reflects the motivation of microtechnical studies exploring 'technological trajectories' associated with specific 'technological paradigms' [*Dosi*, 1982]. For such studies it is critical to:

"*identify with sufficient precision the "dimensions" which characterize each broad technological paradigm and differentiate it from others…* d*efine the 'difficult puzzles' and unsolved difficulties of a technology which are often a necessary (although not sufficient) condition for the search for other ones… describe the transition from one technological path to another and assess* *the factors which allow the emergence of a 'winning' technology"* [*Dosi,* 1982].

These roadmapping framework-based studies of technological change [*Featherston et al.,* 2016; *Featherston, O'Sullivan,* 2017; *Ho, O'Sullivan,* 2019; *Park et al.,* 2020; *Phaal et al.,* 2004b] have identified a number of potentially transferrable methodological lessons, effective practices and sources of evidence, some of which are part of existing roadmapping foresight processes, including:

Integrating and comparing evidence from a variety of sources: Complementing evidence gathered through workshops with national statistics, data from industry analyses, or studies by government organizations, national academies, etc. These studies often contain (semi-) quantitative data of various types, including the analysis of patent data, bibliometrics, market data, and relevant national economic accounts data. The graphical nature of roadmapping allows for the effective comparison of quantitative evidence (e.g. from market analyses, standards databases, patent databases, etc) with qualitative information about key events (and vice versa). In particular, it is possible to graphically overlay trend data with qualitative data points on a roadmap canvas and explore potential correlations (or inconsistencies) between, for example, key scientific, technology demonstration or business events with any inflection points in bibliometric, patent, or market data.

Characterizing and sampling innovation system stakeholder perspectives: When gathering evidence and insights from literature and archival sources, the roadmapping 'layers' (corresponding to categories of industrial-innovation functional activity) can also be used to characterize the perspective of the stakeholders providing the data[3] as well as their national innovation system and sectoral innovation system contexts. This offers a systematic way of monitoring the sampling and consistency of stakeholder perspectives and inputs. In this context, the roadmapping functional perspective categories and innovation system boundaries enable researchers to compare (and potentially reconcile) different perspectives around the importance, interdependencies, and impact of particular innovation events and activities, barriers and enablers.

'Zooming-in' on key innovation events, barriers, linkages: The scalable roadmapping-based frameworks proved highly effective in supporting researchers to 'zoom in' on important micro-technical details which may have influenced the path dependencies of technology innovation journeys. In particular, where appropriate, researchers were able to study key roadmap features with greater granularity, introducing new roadmapping sublayers which distinguished, for example, between different types of technology (e.g. product, measurement tools and systems technologies); between varieties of R&D activities; and between different categories of institution (e.g. types of standards and regulations). Furthermore, the visual nature of the roadmapping approach means that the roadmapping-based tool can more effectively reveal temporal relationships between key events in different innovation activity domains. [*Park et al.,* 2020].

Assessing evidence adequacy: While foresight evidence patterns within the roadmapping canvas helped identify *potential* requirements for further analysis (greater granularity, more careful analysis of innovation linkages, or finer stakeholder sampling, etc.), judgements needed to be made about the added value of more granular evidence on particular features. In this context, researchers typically developed tests for the adequacy of evidence gathered for particular regions or features of the roadmap canvas. In particular, if the identification of new key roadmap features (events, barriers, linkages) 'saturates' – i.e. no new features deemed influential to the innovation dynamics being studied are being added to the mapping canvas, then investment in further iterations of analysis may not be justified.

In summary, the use of the roadmapping canvas as a research tool to study technology trajectories has highlighted the importance of obtaining sufficient granularity of evidence and triangulation of stakeholder perspectives to identify and understand the key factors influencing innovation path dependencies. In particular, these research studies point to the potential of the roadmapping framework as a diagnostic tool to examine the sufficiency, efficacy, and credibility of evidence related to technology innovation pathways.

Discussion: Foresight Evidence Patterns and Agile Roadmapping

In this section, we revisit the key foresight evaluation principles and evidence challenges within the visual organization of the roadmapping canvas. In particular, we investigate the potential of roadmapping frameworks to more effectively monitor and regulate the collection of strategic foresight evidence. We explore how some of the distinctive features of the roadmapping framework offer enhanced opportunities to address the challenges of ensuring the relevance and usability of foresight analyses; and to enhance granularity, coverage, and consensus of roadmapping data.

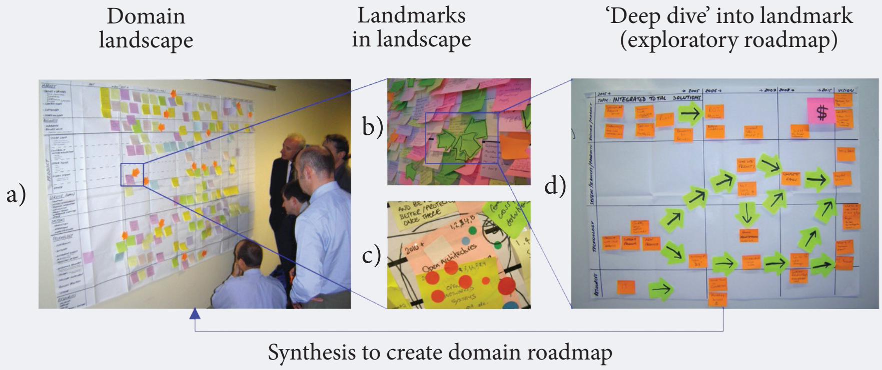
We start this section by summarizing roadmapping practices, outlining typical approaches to gathering inputs from stakeholders, capturing evidence and insights, and representing these graphically within the roadmapping canvas. We go on to explore data patterns associated with the foresight 'sources of error'. In particular, we examine patterns of evidence (related to particular innovation activities or dynamics) that may require more granular detail, broader stakeholder input, more attention to particular innovation system elements, or lifecycle phases. We conclude by highlighting how the iterative structure of roadmapping processes offers decision points when the overall strategy foresight exercise could be adapted and reconfigured (in terms of scope, focus, and prioritization of effort/resources) to ensure greater accuracy, credibility and utility.

Situations for Applying Enhanced Methods for Gathering Roadmapping Evidence, Insights, and Priorities

In practice, most roadmapping exercises involve facilitated workshops, in addition to other activities, where participants contribute information, priorities, and insights, which are collected and organized within the roadmapping architecture. A common approach is to use large wall charts (paper or digital), structured using the roadmap architecture, as the focus for the foresight activities [*Phaal et al.,* 2007]. Sticky notes are often used as a mechanism for participants to contribute insights and evidence (Figure 2). As part of a facilitated process, participants identify specific innovation events, barriers, and opportunities they believe are important. They are also encouraged to articulate more general insights and perspectives they believe are relevant to the innovation dynamics being studied in the workshop.

[3] e.g. scientists, technology engineers, manufacturing engineers, economists, market analysts, policy researchers, and analysts, etc.

Figure 2. **Domain Landscape**



Note: (a) Photograph of domain landscape; (b) arrows highlighting important 'landmarks'; (c) coloured dot stickers capturing different stakeholders' prioritization; (d) 'deep dive' exploration of innovation dynamics related to particular roadmap 'landmarks'

Source: authors.

The roadmap layers (and sublayers) are used as a checklist to stimulate the generation of ideas. Inputs can include a wide variety of information types, from important innovation trends and drivers, strategic opportunity options, key innovation activities to barriers and risks, speculation and scenarios; as well as strategic planning information, milestones, and goals. Different types of information are typically added at different phases of the roadmapping foresight process. These different stages are discussed below.

As described by [*Phaal et al.*, 2007], *the* key metric used in populating the roadmapping canvas is the density and distribution of sticky notes. When participants identify links between roadmap content then these are often captured by drawing connecting arrows. The contributions of individual participants can be analyzed to reveal clusters of similar features and ideas (Figure 2b), before duplicates are removed (or rationalized) and key events and/or opportunities are collectively prioritized. A common workshop practice for prioritizing opportunities is to use a 'sticker vote' technique, where participants vote on the importance of key roadmap features by adding small colored 'dot' stickers adjacent to the relevant opportunity or event on the roadmap canvas (Figure 2c). The votes are counted by the facilitators to identify the most interesting roadmapping opportunities within a 'domain landscape'. The roadmapping exercise may then involve a number of 'deep dive' analyses of particular roadmapping features or 'landmarks' (Figure 1d). The insights from this analysis are then synthesized with information from other deep dives to enrich the information captured within the overall roadmapping canvas.

The roadmapping practices described above illustrate how the focus of a roadmapping exercise can be adapted to investigate key aspects of the emerging understanding of innovation pathways. In particular, it is possible to explore particular innovation activities, linkages, and dynamics in greater detail to distinguish between different stakeholder perspectives and priorities, and iteratively synthesize the new insights into an increasingly richly populated roadmapping canvas. These benefits can be rapidly realized even for large-scale foresight initiatives, in a one- or two-day workshop with carefully selected participants, as a first (often design) iteration for a more substantial foresight initiative, or as a one-off diagnostic.

In the following sections, we explore how some of the distinctive scalability and systemic features of the roadmapping framework offer enhanced opportunities for the monitoring and regulation of foresight evidence collection, addressing the challenges of ensuring the relevance and usability of foresight analyses and the potential to enhance granularity, coverage, and consensus of roadmapping data.

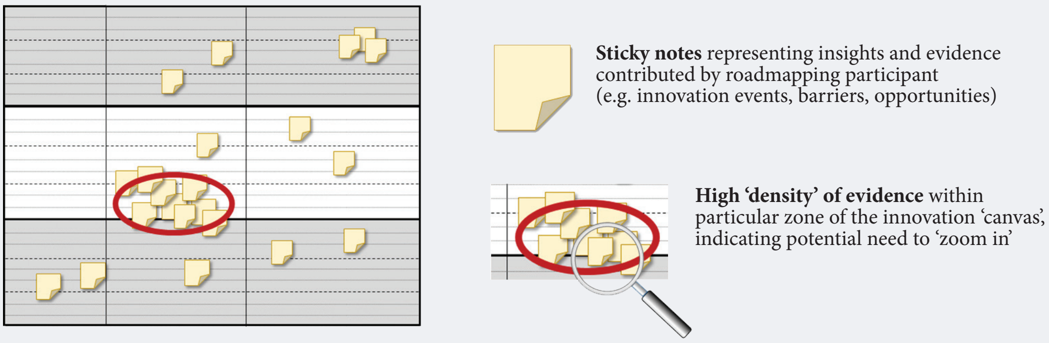
Event Distribution Patterns: The Density (or Absence) of Stakeholder Inputs Within Particular Regions of the Roadmapping Canvas

As discussed above, key metrics used when considering the evidence population of a roadmapping canvas are the density, connections, and distribution of sticky notes. Figure 3 schematically illustrates how roadmapping evidence can be concentrated within a particular zone of the roadmap's innovation canvas. This high density clustering of information (within adjacent layers related to particular sets of innovation activities, within a particular innovation time window) signals a convergence of attention by participants on a zone of innovation dynamics perceived as important to determining the technology trajectory and innovation pathways. A high density of stakeholder inputs in a particular region of the roadmapping canvas may signal an important area of innovation dynamics, which merits more careful and detailed consideration. Such clusters should be scrutinized within the facilitated workshop and potentially examined in greater detail in a further iteration of the analysis – zooming in on the region of interest with more 'granular' roadmapping layers corresponding to more specific categories of innovation activity.

In scrutinizing clusters of evidence within the roadmapping canvas, it may also be important to analyze the level of consensus and sampling of innovation system stakeholder perspectives. For example, a set of participant inputs clustered within the roadmapping canvas may be coming from only one specific stakeholder group. This in turn may reflect the insights and expertise of that particular group, or it may reflect a lack of consensus or variation in priorities. As illustrated in Figure 4, it may be important to distinguish between and analyze the sampling of stakeholder perspectives. Significant levels of variance between stakeholder perspectives may need to be reconciled, either within a facilitated workshop setting or by examining the issue in a further iteration of the analysis involving appropriately augmented stakeholder groups.

Similarly, it may be important to capture and scrutinize stakeholder inputs both in terms of the level of confidence they

Figure 3. **Density of Roadmapping Objects (Events, Barriers, etc)**



Source: authors.

have in issues or features they have highlighted, as well as their expertise in the relevant innovation activities. As schematically illustrated in Figure 5, clusters of inputs may vary in terms of the underpinning confidence levels of the participants or the relevance of their expertise. Clusters of evidence with significant numbers of inputs with low confidence or low expertise may need to be examined further to diagnose lack of confidence in an input (e.g. related to the probability of an innovation event happening or the importance of an innovation activity). Clusters of inputs by participants in areas of perceived importance, but where there is limited expertise, may need to be examined in a further iteration of the analysis involving participants with relevant specialities.

Many clusters of evidence occur within particular 'zones' of the roadmapping canvas, associated with adjacent layers on the framework and a particular period of innovation activity. The relative positioning of particular roadmapping layers within the architecture reflects a general sequencing of innovation activities from technology R&D to product and market development. Interactions and feedback loops can, of course, occur between the layers – reflecting the non-linear nature of the innovation process. In this context, not all important evidence patterns will necessarily reside in adjoining roadmap layers. The importance of identifying patterns involving linkages between roadmapping evidence (innovation events, activities, barriers, etc) is highlighted in the following section.

Linkage Patterns: The Spread and Span of Roadmapping Linkages across the Roadmapping Canvas

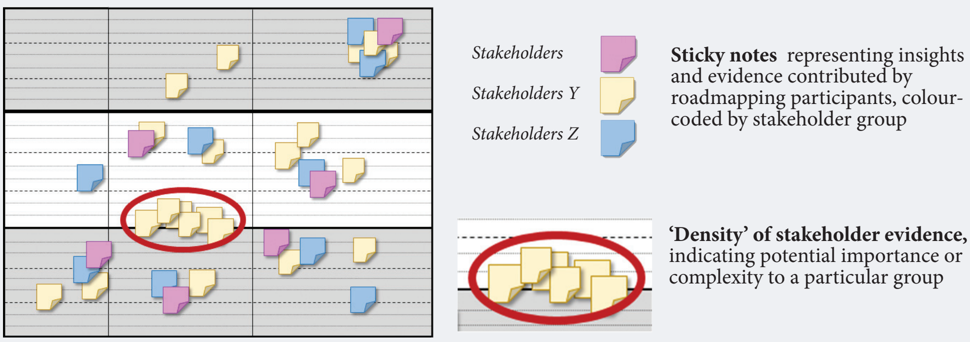
As discussed above, roadmapping participants are encouraged to highlight important linkages between roadmapping landmarks, including linkages between features within non-adjacent regions of the roadmapping canvas.

There are a number of roadmapping evidence linkage patterns which merit attention. In particular, some roadmapping landmarks (especially those related to catalytic innovation events or rate limiting innovation activities) can be linked to a multiplicity of other features on the roadmapping canvas. This density and spread of linkages is schematically illustrated in Figure 6.

Roadmapping landmarks with a high number of linkages to a range of other roadmap layers and objects may need to be analyzed further, potentially by examining the issue in a further iteration of the analysis involving additional expertise associated with the innovation activities which are being linked to from the landmark roadmap feature.

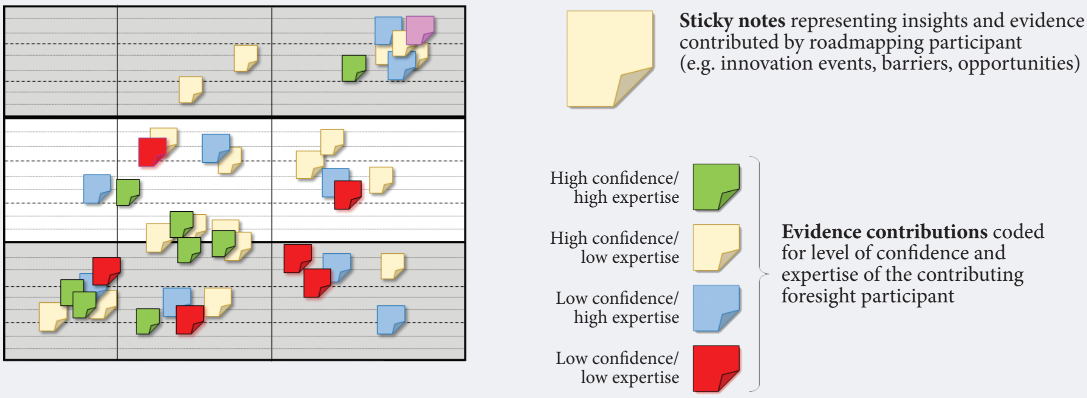
As discussed above, the relative positioning of particular roadmapping layers within the architecture reflects a general sequencing of innovation activities from technology R&D to product and market development. Linkages between innovation features which are spatially separated on the roadmapping canvas are, in reality, generally mediated by some or all

Figure 4. **Density of Perceived Importance of Innovation Roadmap 'Object' by a Single Stakeholder Group Perspective**



Source: authors.

Figure 5. **Variations in Stakeholder Confidence/Expertise in an Object They Have Contributed to the Roadmap**



Source: authors.

of the intervening innovation activity layers. In this context, 'long' linkages identified by roadmapping participants – i.e., those without 'stepping stone' connections through intermediating innovation activity layers – may indicate the need to further analyze the intermediating innovation pathways to identify any barriers along the way. A schematic illustration of a long linkage between innovation objects on the roadmap canvas is represented in Figure 7.

In this paper, we have focused in particular on the importance of generating roadmapping foresight evidence to support the development of strategies for emerging technologies. Under these circumstances, the roadmapping evidence needs to help reveal information on potential technology innovation pathways – from technology R&D, application demonstration, product design, industrialization, and business model/market development.

In this context, the roadmapping canvas can also be used to capture strategic information from participants. In particular, the roadmap can be used to capture potential milestones and intermediate strategic goals. It can also highlight potential innovation pathways linking them. A schematic illustration of the series of linkages indicating a potential innovation pathway from technology proof of concept to a final strategic opportunity goal is captured in Figure 8.

The evidence patterns described above are all signals that particular innovation activities and dynamics may need to be studied more carefully. In particular, as the understanding of potential innovation pathways becomes clearer, there may be a need to adapt the roadmapping exercise to scrutinize particular clusters of evidence, linkages, and stakeholder consensus.

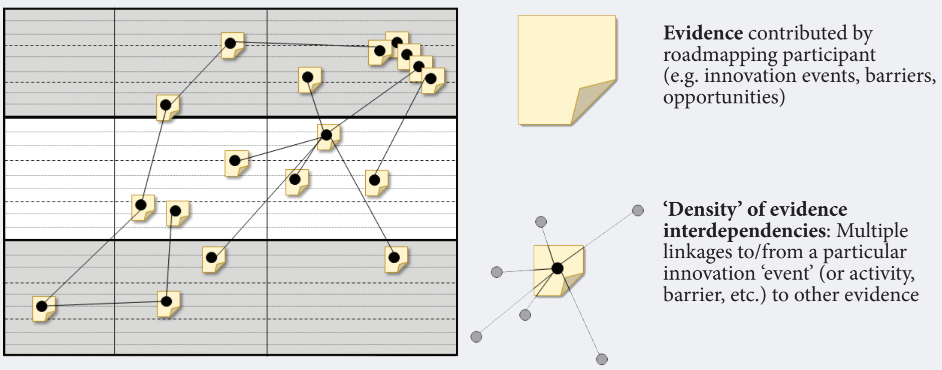
Evidence Patterns and Roadmapping Process Adaptation

In this section, we explore how the different phases and stages of the roadmapping process offer the opportunity to re-scope, re-prioritize, and re-focus foresight efforts and resources to enhance the granularity, coverage, consensus, and strategic relevance of the evidence generated.

As discussed above, the collection, integration, and synthesis of foresight evidence within the roadmapping canvas typically happens within a sequence of steps or phases, including:

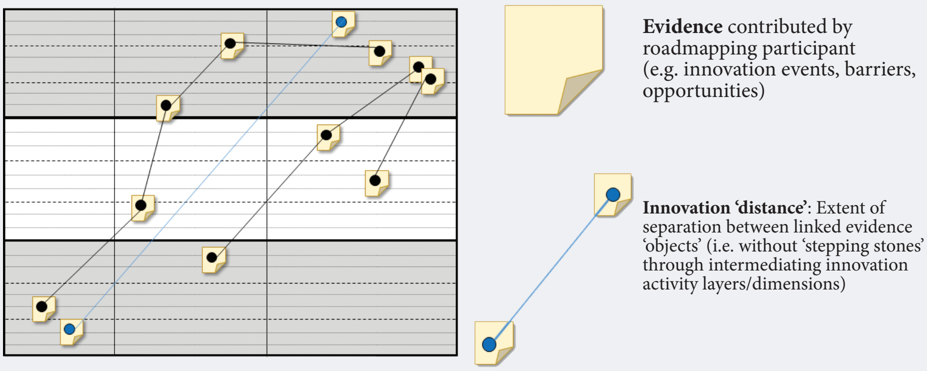
- **Establishing a vision**: Scanning trends, opportunities/challenges and establishing a consensus vision among participants;
- **Exploring a 'landscape'** of capabilities and opportunities: surveying current (and potential) capabilities and opportunities; evaluating the relevance of particular capabilities to address opportunities; identifying innova-

Figure 6. **Multiplicity of Interdependencies/Linkages from a Particular Roadmapping Object to a Range of Other Dispersed Innovation System Activities**



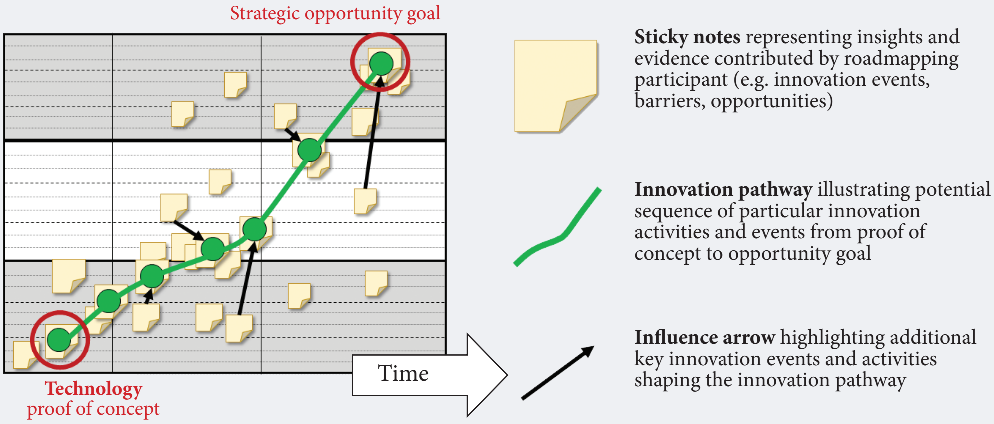
Source: authors.

Figure 7. **Differences in the 'Distance' between Linked Innovation 'Objects' on the Roadmap Canvas**



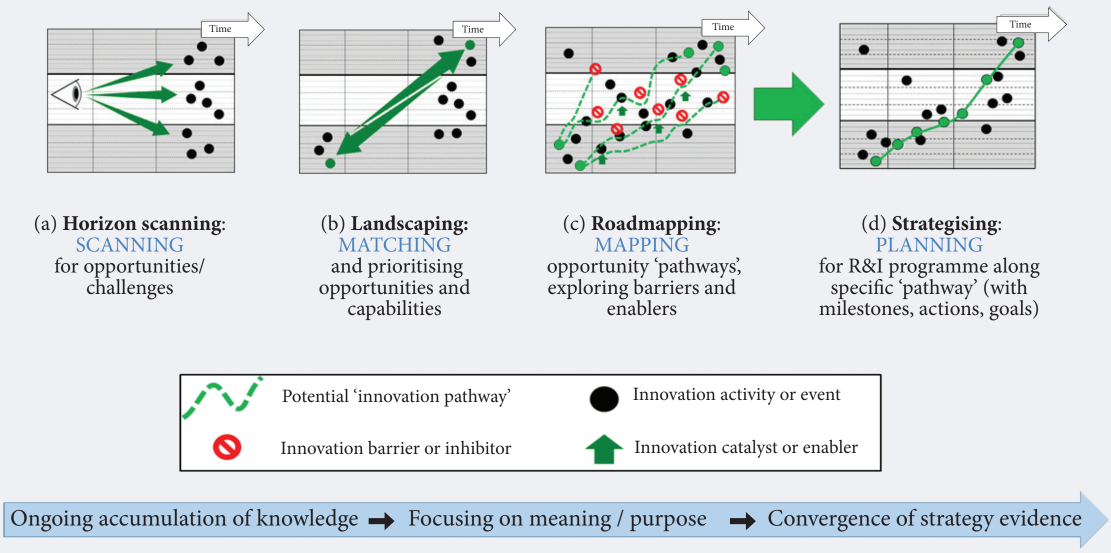
Source: authors.

Figure 8. **Series of Linkages Indicating a Potential Innovation Pathway from Technology Proof of Concept to a Final Strategic Opportunity Goal**



Source: authors.

Figure 9. **Variations in Evidence Emphasis within the Roadmap Canvas for Different Phases of Foresight Analysis**



Source: authors.

Table 3. **Main Focus Areas of Roadmapping**

Phase	Contents
1. Establishing a vision	The roadmapping participant inputs (dot votes) are focused on longer term potential opportunities and future innovation system features, systems, and technology breakthroughs
2. Exploring the landscape	The roadmapping participant contributions are focused on surveying current (and potential) capabilities and relevant future opportunities; evaluating the relevance (and strengths) of those capabilities to address the opportunities
3. Mapping potential innovation pathways	The roadmapping participant contributions are focused on investigating strategic pathway options (navigating barriers, filling requirement gaps, identifying potential milestones, etc)

Source: authors.

tion barriers and requirement gaps; and prioritizing innovation opportunity 'destinations';

- **Revealing innovation pathways**: Investigating strategic innovation pathway options – navigating innovation barriers, filling requirements gaps, leveraging enabling factors, and identifying potential intermediate goals and milestones.

These stages are followed by a process of translating the foresight outputs into the strategic planning exercises of STI stakeholder organizations (including informing strategic technology selection and R&D investment processes).

The population of the roadmapping canvas with evidence for the different phases of 'scanning', 'landscaping', 'roadmapping', and (pathway) 'planning' is illustrated schematically in Figure 9. The dots scattered on each canvas correspond to new inputs contributed by roadmapping participants in each phase, with the patterns reflecting the foresight emphasis at each stage.

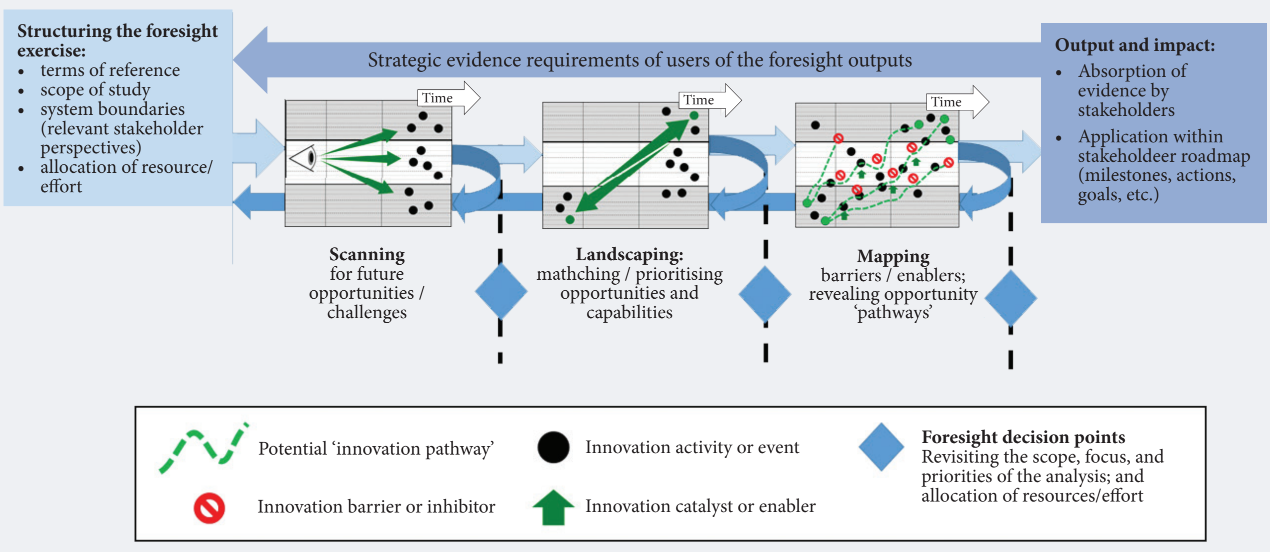
Each roadmap canvas schematic is separated into three layers (corresponding to the dimensions discussed above). As before, the top layer captures evidence and insights related to trends and drivers relevant to the goals of the mapping activity; the middle layer captures evidence related to systems that need to be developed to address the opportunities; and the bottom layer captures inputs related to the enablers and resources (including science & technology research) (Table 3).

Following the formal roadmapping foresight exercise, there will be a stakeholder planning phase (4), where the foresight outputs will be translated into STI organizations and used for their strategic planning purposes. In particular, the focus of these exercises will be on generating strategic inputs as part of selecting particular strategic pathways (including specific milestones, intermediate innovation 'stretch goals' and final strategic objective goals).

The iterative nature of the extended roadmapping exercise is illustrated in Figure 10, highlighting the ongoing interplay between exploratory, normative, and strategic analyses. This figure also identifies potential decision points between key stages of the analysis, offering opportunities to revisit the scope, focus, and priorities of the roadmapping exercise, and make any appropriate revisions to the allocation of resources and effort.

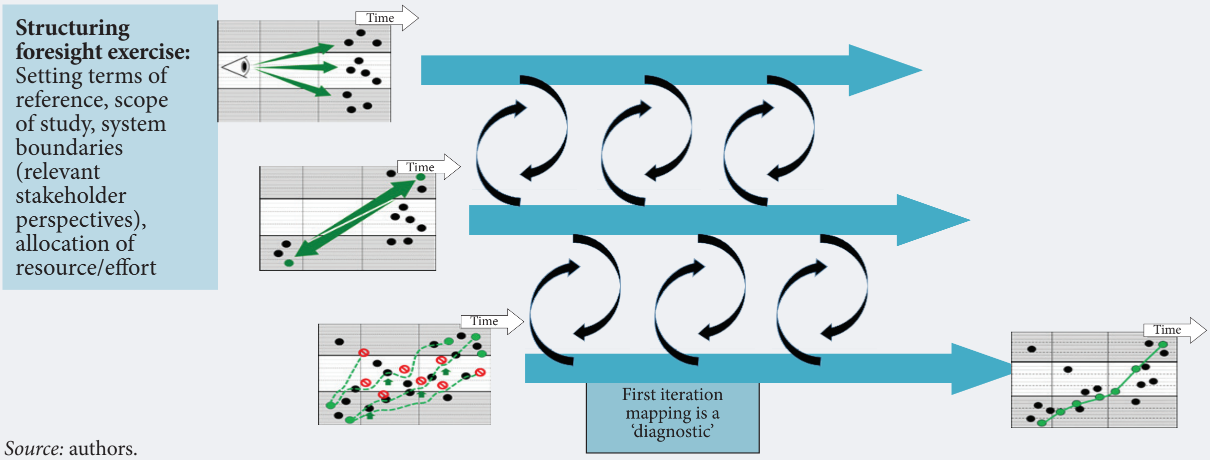
The figure also illustrates the push-pull dynamic between the initial scope and ambition of analysis set by commissioners of foresight exercises and the evidence requirements of innovation stakeholders (who will use the outputs to develop their strategies). This dynamic underpins the tension between the resources and efforts allocated to carry out a foresight exercise and the granularity, credibility, and efficacy of the evidence gathered. It is only as the roadmapping exercise progresses – and the landscape features and potential innovation pathways start to emerge – that it will start to become clearer which areas of the roadmapping canvas will require greater attention and whether the evidence requirements of future roadmap users can be achieved. In this context, it is critical that the roadmapping process is adaptive, iterative, and agile. There are opportunities to re-focus, re-scope, and re-prioritize foresight efforts in response to the complexity of the innovation system dynamics being explored.

Figure 10. **Iterative Nature of the Extended Roadmapping Exercise, Involving Ongoing Interplay between Exploratory, Normative, and Strategic Analyses**



Source: authors.

Figure 11. **Iterative Nature of the Extended Roadmapping Exercise, Involving an Ongoing Interplay between Scanning, Landscaping, and Mapping Analyses**



Source: authors.

In practice, roadmapping-based foresight efforts involve ongoing feedback loops between exploratory and normative analyses as well as strategic planning exercises. There can be any number of iterations involving roadmapping workshops (and integration and synthesis of evidence from complementary foresight analyses). Indeed, roadmaps may be updated by stakeholders at regular intervals beyond the lifetime of a particular foresight exercise or strategic planning lifecycle. This ongoing interplay between scanning, landscaping, and mapping analyses is illustrated in Figure 11.

The iterative and adaptive nature of roadmapping processes, combined with a roadmapping framework which can facilitate the monitoring and regulation of evidence offers the potential to significantly enhance the granularity, efficacy, and credibility of foresight outputs. In the following section, we summarize the ideas discussed in the previous sections into a set of 'principles for adaptive roadmapping'.

Implications for Foresight Practice and Application: Principles for Adaptive, Effective Roadmapping

There are significant challenges in ensuring the outputs of roadmapping foresight exercises meet the evidence requirements for technology strategy development in STI agencies and research & technology development (RTD) organizations. In many cases, the monitoring and regulation of evidence-gathering related to technology innovation pathways does not effectively adapt as critical elements of the complex innovation system dynamics are revealed. Without a systematic approach to adaptively re-scoping and re-focusing foresight resources and efforts, it is difficult to ensure the roadmapping outputs are strategically relevant, detailed, and credible for users. In order to reduce sources of 'evidence failure' and increase user impact, the following adaptive roadmapping principles are important:

Design the scope and focus of the roadmapping study in the context of foresight users' strategic evidence requirements: For those roadmapping studies where the outputs are intended to inform strategy development at STI policy agencies and R&D organizations, it is important for those commissioning roadmapping studies to have early and ongoing engagement with intended users. In particular, the scope and focus of the study should be structured to ensure the evidence/insights generated are focused on the right units of analysis and the right granularity of detail. If this is not the case, the transition from a foresight evidence base and analysis of potential innovation pathways into the strategy development process of an STI stakeholder (see Figure 9(c)-(d)) may not be effective.

The dimensions and phases of the roadmapping framework canvas should be structured accordingly to ensure outputs in a format that is fit-for-purpose, absorbable by intended users, and can ensure the timelines considered are relevant in the context of the lifecycles of government STI policies, agency programs, and RTD organization planning.

Allocate sufficient time and resources to meet the granularity of evidence requirements (and revisit the distribution of resources and efforts as evidence is gathered): There is an inevitable push-pull dynamic between the scope of analysis set by commissioners of foresight exercises and the evidence requirements of innovation stakeholders using the outputs to develop strategies. This dynamic underpins the tension between the resources and effort allocated to a foresight exercise and the granularity/efficacy of evidence gathered.

When foresight evidence patterns (within the roadmapping canvas) suggest a need for further analysis (see Figures 3-7), there may not be sufficient resources (or time) available within the originally designed foresight exercise. In this context, decisions will have to be made about potentially narrowing the scope of the analysis to achieve the required granularity and sampling of key issues, or further resources may need to be requested. Again, the patterns of evidence within the roadmapping canvas (Figures 3-7) may offer insights into how the exercise could be effectively re-bounded in scope (without compromising on accuracy in critical areas). In particular, earlier iterations of the scanning or landscaping analyses should reveal opportunities to reprioritize and refocus attention on particular innovation events and activities (which are critical to determining the trajectories of technology innovation pathways).

Take an adaptive and iterative approach to scoping, focusing, and sampling roadmapping foresight evidence: The gathering, integration, and synthesis of foresight evidence within a roadmapping canvas typically happens within a sequence of steps or phases. In particular, roadmapping exercises generally involve phases of exploratory, normative, and strategic (options) analysis (see Figures 10 and 11). These phases offer potential decision points for foresight adaptation. In particular, there are opportunities within the extended foresight exercise, at feedback stages between scanning, landscaping, and mapping analyses to revisit the scope, focus, and priorities of the analysis, and make any appropriate revisions to the allocation of resources and effort (as discussed above).

Systematically scrutinize different categories of evidence patterns to identify areas requiring more careful analysis: The visual nature of the roadmapping framework canvas (and its underpinning innovation system architecture) offers the opportunity to graphically reveal different categories of evidence patterns, which may signal a need for more detailed and careful analysis, in particular: ***(1) evidence cluster patterns**, i.e.* where there is a high density concentration of participant inputs (see Figures 3 and 4), signaling a convergence of attention on a zone of innovation dynamics, which may merit more careful and detailed consideration; (2) ***evidence linkage patterns***, i.e. where there is a significant spread and span of roadmapping linkages from a particular landmark across the roadmapping canvas (Figures 6 and 7), signaling the identification of a roadmapping feature with potentially complex innovation system dependencies; and (3) ***stakeholder input patterns***, i.e. where there is significant variance in the consensus, confidence, and sampling of innovation system stakeholders around innovation events and system linkages (See Figure 8).

Apply tests to determine evidence adequacy and relevance: While foresight evidence patterns within the roadmapping canvas may identify a *potential* need for further analysis (greater granularity, more careful analysis of innovation linkages, or finer stakeholder sampling, etc.), a judgement will need to be made about the likely diminishing strategic returns of gathering additional evidence at each iteration. In this context, it will be important to develop tests for the adequacy of evidence at different phases of the analysis, in particular: (a) If further detail or finer sampling has not significantly changed the characterization of key events or the trajectories of key innovation pathways revealed in the roadmap, then investment in further iterations of analysis may not be justified. (b) If the extra detail from further iterations would go beyond the granularity of the strategy development needs of the users of the foresight outputs, then investment in further iterations of analysis may not be justified

Implications for Theory and Research Methods

In the previous sections, we explored the potential of the roadmapping canvas framework to effectively structure the collection, organization, and analysis of foresight evidence. In addition to the implications for STI foresight practice, we argue that the practice-based roadmapping architecture has the potential to offer a flexible, scalable framework for academic study of innovation system dynamics and technological change, as well as informing our understanding of the process of foresight itself.

In this paper we explored the extended foresight process (from the commissioning of a study to the development of a foresight-informed strategy) within the visual organization of the roadmapping canvas. The graphical representation of key distributions of evidence patterns at different phases of foresight offers some semantic clarity and precision in distinguishing exploratory, normative, and strategic analyses (and emphasizing their interdependence). In particular, we highlight distinct phases of foresight effort: scanning, landscaping, mapping, and planning (see description in Table 1). In representing foresight evidence within the roadmapping framework, we introduce the notion of the 'innovation pathway' as an important object of STI strategic foresight analysis – i.e., a continuous journey through the roadmapping canvas of different innovation system functions (Figure 8 and Figure 9(c)-(d)), starting with a particular STI-based capability and ending with a particular socioeconomic impact opportunity. This concept helps reveal what types of evidence are needed, how this evolves throughout the foresight process, and where there might be gaps. For example, if there is insufficient evidence to support an understanding of potential pathways, it will be more challenging for users to apply foresight evidence into strategy development. Without sufficient granularity to determine the path dependencies of the innovation trajectory, the evidence base may be inadequate. Similarly, without relevant innovation stakeholder perspectives informing the different stages of the entire innovation pathway, the evidence may not be credible.

More generally, the graphical representation of foresight evidence at different stages of the process highlights the inherent unknowns at the beginning of a foresight process and the importance of adaptation and iteration. At the commissioning stage of a foresight exercise, one cannot fully anticipate how complex the dynamics of a particular technology innovation pathway might be. One cannot, ab initio, know what level of microtechnical innovation detail may be required in order to determine potential innovation 'path[way] dependencies'. Similarly, one cannot anticipate the level of consensus or disagreement among innovation stakeholders regarding key events, trends, barriers, priorities, and so on influencing the innovation pathways. It becomes very clear that at the beginning of a foresight process, it will not always be possible to fully identify the right cohort of foresight participants (i.e. appropriate mix of perspectives and expertise) or strike the right balance of exercise scope and resources (in order to ensure outputs are sufficiently granular, focused, and credible to be actionable). Consequently, strategic foresight analysis of highly complex technology innovation systems must be both adaptive and iterative, if it is likely to ensure its outputs that are useful, trusted, and used.

Finally, we suggest that the specific patterns of evidence/information within the canvas highlighted above should also be useful in supporting academic research studies of technological emergence or socio-technical change. Again, the patterns (and associated principles) should help reveal where evidence on particular innovation activities or dynamics may require more granular detail, broader stakeholder input or more attention to particular innovation system elements or lifecycle phases.

Implications for Practice and Future Research

This paper explores the challenges of carrying out effective strategic technology roadmapping at the national innovation system-level or sector-level. We focus on roadmapping exercises designed to inform the STI strategies of policymakers and R&D agency officials (although the approach and findings may be transferable to firm-level or non-technology-focused foresight). In particular, we highlight the difficulties of ensuring that the outputs of foresight exercises have the right level of detail, scope, and stakeholder confidence to support the strategy development needs of the STI policymakers and agency officials.

While the literature offers some insights on sources of error, evidence limitations, and how to evaluate foresight and roadmaps, there is limited guidance on how to improve strategic foresight processes, performance, and impact. In particular, there is limited guidance on how to identify and mitigate deficiencies in foresight evidence granularity, relevance, and credibility as a foresight process is carried out and evolves.

This paper reviewed the use of roadmapping as a foresight and strategy tool, highlighting distinctive features and functions by comparison with other foresight tools. We examined the application of roadmapping frameworks as an innovation research tool (to study emerging technology innovation dynamics and sociotechnical change). In particular, we highlighted how the distinctive features of the roadmapping canvas offers the potential for its application as a diagnostic tool to examine the sufficiency, efficacy, and credibility of strategic foresight evidence as it is gathered.

We argue that the distinctive features of roadmapping frameworks and processes offer the potential to more effectively monitor and regulate the collection of strategic foresight evidence. In particular, we highlight how the visual organization of roadmapping within an innovation systems perspective means that specific patterns of evidence within the canvas can signal where evidence on particular innovation activities or dynamics may require more granular detail, broader stakeholder input, more attention to particular innovation system elements, or lifecycle phases.

Furthermore, we outline how the iterative structure of roadmapping processes offers decision points where the overall strategy foresight exercise could be adapted and reconfigured (in terms of scope, focus, and prioritization of effort/resources) to ensure greater accuracy, credibility, and utility. In particular, we highlight the potential for reflection points between phases of 'scanning' (for future opportunities/challenges); 'landscaping' (the layout of capabilities and opportunities); 'mapping' (potential strategic pathways); and 'strategizing' (for milestones, activities, and goals). In doing so we offer some semantic precision (and hopefully clarity) for these common foresight terms.

Reflecting on the implications for roadmapping practice, we propose five '***principles for adaptive roadmapping***':

1. Design the scope and focus of the roadmapping study in the context of foresight users' strategic evidence requirements
2. Design (and revisit) the allocation of time and resources to meet the granularity of evidence requirements
3. Take an adaptive and iterative approach to scoping, focusing, and sampling roadmapping foresight evidence
4. Systematically scrutinize different categories of evidence patterns to identify areas requiring more careful analysis
5. Apply tests to determine whether the evidence base is adequate (in terms of precision), sufficient (in terms of sampling), and relevant (in terms of user requirements and utility)

The principles proposed above are a preliminary set of methodological guidelines. Further work should test and refine these approaches in practice and identify other categories of evidence patterns for signals of evidence quality. Further work should investigate the potential to apply particular data analysis tools and methods (e.g., the Design System Matrix [*Browning,* 2001]), as well as opportunities offered by the application of digital tools to roadmapping exercises (capturing participant inputs in more structured ways; integrating data from other foresight analyses more systematically, etc). Further work should also investigate the implications of this work for other foresight methods, in particular the relevance, importance, and transferability of the 'agile' approach and principles.

Finally, the ability of the roadmapping canvas to effectively organize and support the analysis of foresight evidence suggests the fundamental roadmapping architecture may have the potential to offer a more general flexible, scalable framework for studying innovation system dynamics and technological change. This enables a better understanding of its utility (and limits), as well as any opportunities to enhance the architecture (or refine it for particular applications).

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