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..

Keywords: 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.

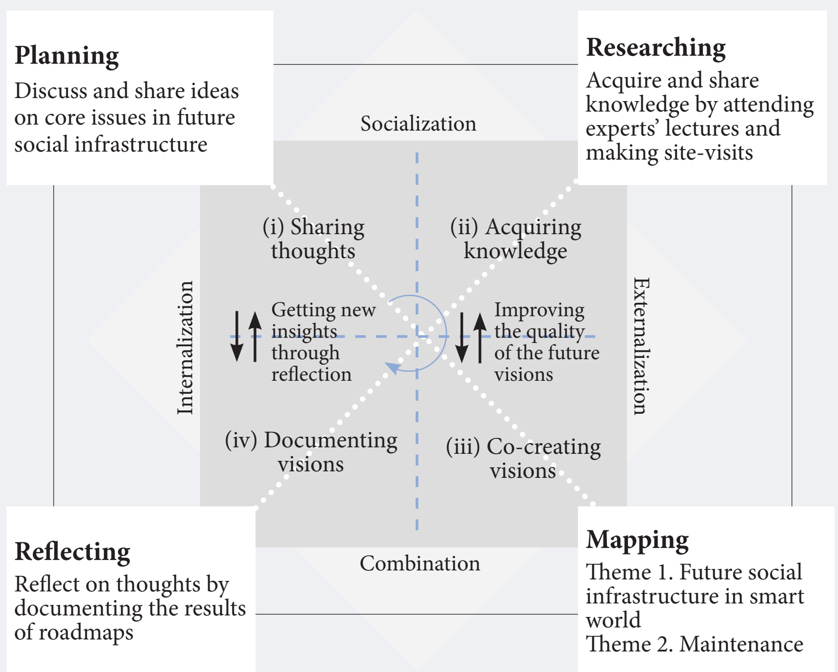
The questions were pre-coded and open-ended questions using a five-point Likert scale. In our analysis of the responses, we carried out statistical processing with the aim of investigating satisfaction. We also carried out primary and secondary coding on the free statements based on the inductive coding 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".

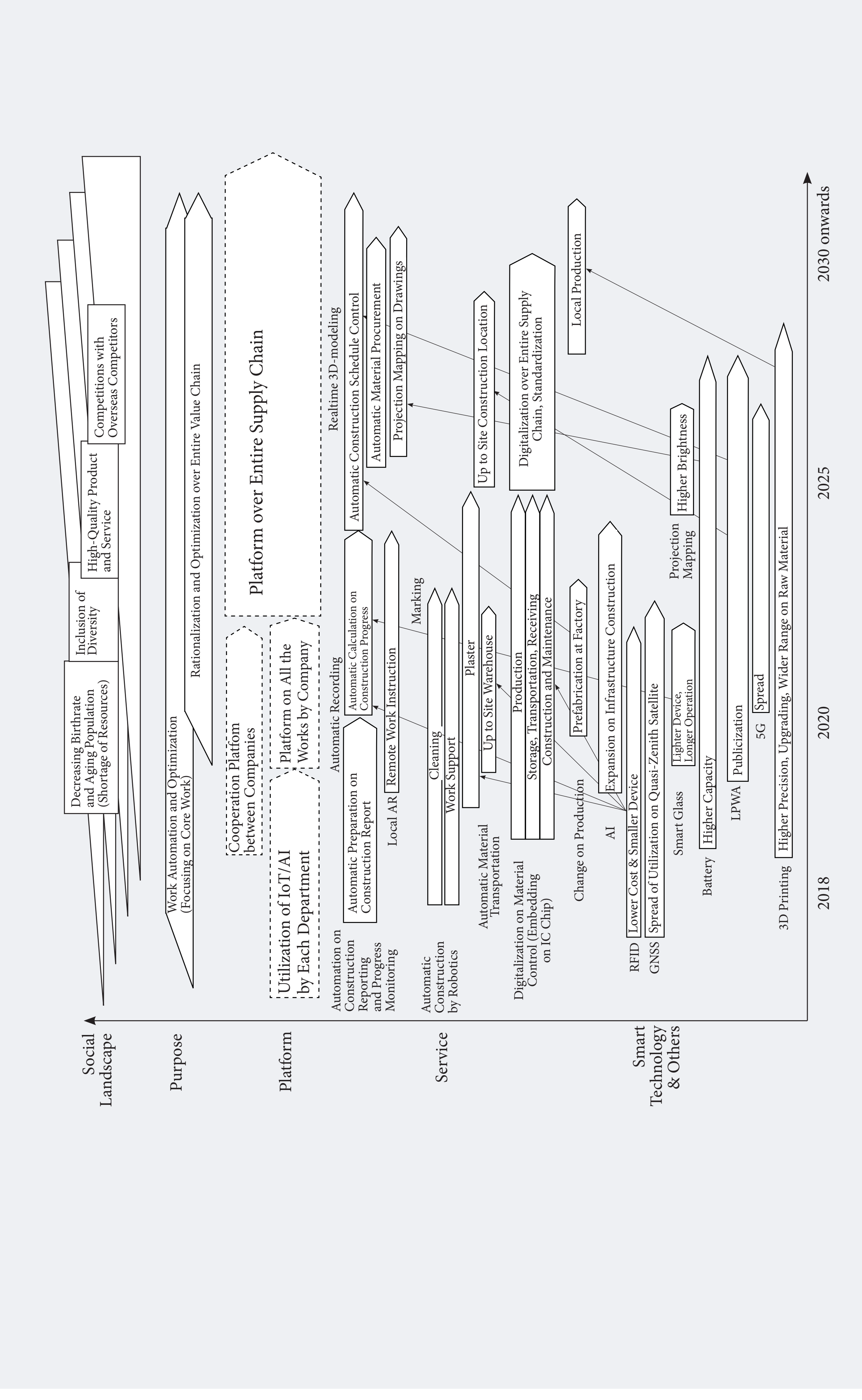
This was a meaningful and learning activity because we were able to acquire knowledge by using the research in the subcommittee and we were able to obtain a more concrete image by implementing a systematic expres-

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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