A conceptual framework of roadmapping for digital service systems in smart cities

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Abstract

Smart cities have gained attention recently as a means of addressing the complex and diverse urban problems. Smart city initiatives are regarded as a systematic transformation to a sustainable city through the design and implementation of a digital service system (DSS) that offers functionality to citizens through the holistic integration of digital technology, urban assets, and physical products. However, DSS implementation often conflicts with current social norms and customs owing to the lack of consideration of the social and human aspects of the target city. This study developed a conceptual framework for the strategic design and implementation of DSS in smart cities. Specifically, technology roadmapping (TRM) is adopted as a core technique. This study suggests DSS roadmapping framework that modified TRM to enable strategic planning of DSS through expressing the interaction between technology and social aspect based on the requirements to be considered in its design and implementation.

Keywords: Digital service systems, Smart city, Technology roadmapping, socio-cyber-physical systems

Introduction

Cities are the focal points of social and industrial activities, housing more than half of the world's population (United Nations, 2019). In addition, cities are likely to encounter considerable issues, such as air pollution, congestion, excessive resource and energy consumption, and issues on waste management and human safety and health. These conditions may lead to an unsustainable future for cities and society, in general.

The smart city initiative has gained attention recently as a means of addressing these complex and diverse urban problems (Washburn et al., 2010). A smart city can be regarded as a systematic transformation of a city into a sustainable one (Eames et al., 2013) through the design and implementation of a digital service system (DSS) that offers functionality to citizens through the holistic integration of digital technology, urban assets, and physical products (Watanabe et al., 2020). The ultimate goal of the smart city initiatives to increase the well-being of citizens through the convenience of public services and the livability of the living environment through the adoption and distribution of DSS.

However, DSS implementation often conflicts with current social norms and customs (e.g., contradiction with the implementation of public policies, social resistance to integrate technology into citizens' life, and opposition to data sharing) (Kummitha & Crutzen, 2017). Therefore, it is necessary to strategically plan and design DSS to predict its impact on urban life in a long-term perspective, considering the interaction between society and technology, as well as between digital and physical environments. Another factor that makes DSS implementation difficult is the heterogeneity of relevant stakeholders (Mueller et al., 2018). As each actor has different aspirations and objectives, it is pivotal to clarify their roles and collaboration governance. Moreover, because the application of data and technology is closely linked to the lives of people, it is also essential to establish a consensus on the functions of the DSS, including not only the actors of the DSS, but also the citizens and government agencies. Without this, the project will be in a state of disarray, which will inhibit its progress. Despite of the above difficulties, existing service system design literatures mainly deal with modeling and defining content of DSS, and not treated strategic planning for DSS implementation in much detail (Mitake et al., 2020).

Technology roadmapping (TRM) is one of the most useful approaches for strategic planning (Carvalho et al., 2013). TRM is adopted as a strategic technology management tool in a wide range of industrial and academic contexts to align technology strategy with corporate vision and to visualize the interactions among the strategic elements to be considered. TRM has been customized and applied for a variety of contexts and purposes because of its adaptability. Indeed, its application has shifted recently from a conventional focus on product and technology development to integrated planning of services and product services, open innovation, and integrated planning of services and data (Kayabay et al., 2022). Furthermore, TRM process provides actors from diverse backgrounds with an opportunity to exchange knowledge and perspectives, and it can provide a means for integrated communication about challenges, opportunities, and new ideas (Phaal, 2004). The qualities listed above suggest that TRM can be utilized as an approach to address the difficulties of developing DSS toward smart cities.

Existing TRM studies have mainly addressed the identification of key technologies that contribute to the realization of smart cities and the development of their technology roadmaps (Lu et al., 2019), as well as the development of roadmapping methods for smart services as a strategic planning approach for companies to realize smart cities (Ibrahim et al., 2018). However, few studies have addressed strategic planning for systemic changes in smart cities (Ben Letaifa, 2015). Even the studies mentioned above have focused only on the development of technological aspect (products, services, and technologies) and ignored planning that considers the social aspects of cities. In addition, there are studies that focus on design approaches and implement visionary designs for the future of a city that includes social aspects (Andreani et al., 2019; Mitake et al., 2020). However, there is still no practical method that addresses strategizing DSS development toward smart cities, which consider comprehensively the long-term perspective, social and technological (physical and cyber space) interactions, and stakeholder heterogeneity described above.

This study entailed a conceptual framework of roadmapping for the strategic design and implementation of DSS in smart cities. TRM, a widely used strategic planning method in industries, was used as a core technique to develop a DSS roadmapping framework by summarizing the set of requirements to be considered in DSS development in cities. The proposed framework consists of a procedure and roadmap format for implementing these requirements.

Roadmapping framework for DSS in smart cities

Requirements for roadmapping of DSS

Based on a brief literature review of TRM and smart city studies, the following are identified as requirements for developing roadmapping framework.

- Co-creation with diverse stakeholders encompassing DSS development

It is crucial that relevant stakeholders are involved in the DSS roadmapping process, as smart cities are achieved through the collaboration of diverse stakeholders (Mueller et al., 2018). Furthermore, it is necessary to develop a tool that enhances participation. Because citizens and the city government have contextual knowledge that is critical in the development of smart cities, it is vital to effectively facilitate communication among stakeholders by organizing their knowledge in a way that may be represented in the roadmap.

- Appropriate formats for DSS roadmapping in cities

The roadmap must define formats according to the context of DSS development in cities. These formats must categorize the components that should be considered when strategizing the design and implementation of DSS in cities. To address this, this study defined the components based on the perspective of socio-cyber-physical systems (SCPSs), which is regarded as “systems constituted by the social world (people), the digital world (data), and the physical world (things)” (Rijswijk et al., 2021). SCPSs are considered a socio-technical systems in which digital artifacts play a vital role in the system's existence and function. Indeed, Cities are complex systems in which social, physical, and information (data) dimensions interact dynamically (Johnson, 2012). Thus, the SCPS lens is suitable for capturing strategic design components for DSS roadmapping.

- Decision support for DSS development priorities

In a large-scale system transformation such as a smart city initiative, multiple DSS development projects are expected to be carried out simultaneously during the development period. Therefore, relevant stakeholders need to make decisions on the priority and development period of each DSS from the viewpoint of the resources they have and the consistency with their visions. The proposed methodology should provide a process and tools to support the above decision-making process.

Roadmapping process

A conceptual framework for DSS roadmapping is developed based on the identified requirements. The following provides detail description of each phase in the proposed framework.

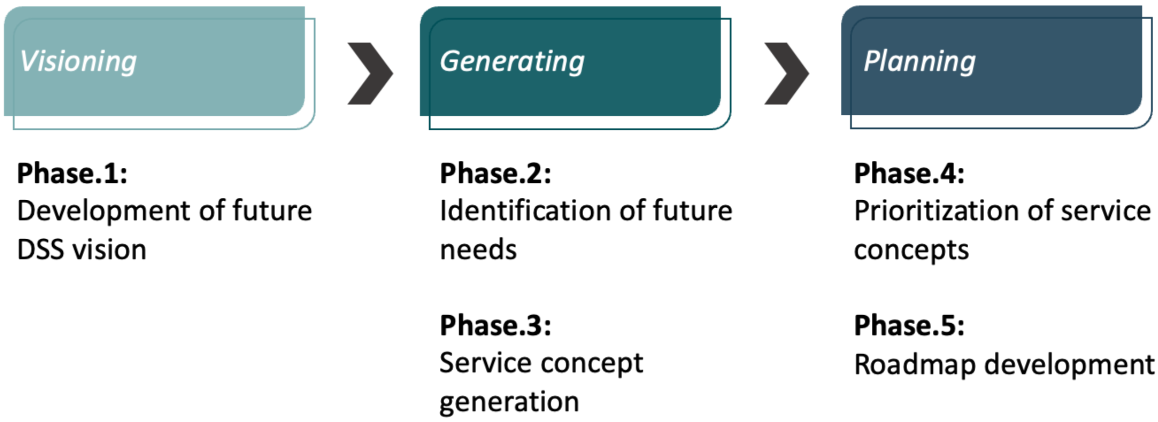

Figure 1. Overview of the proposed framework.

<u>Phase 1: Development of future DSS vision</u>

The first phase is to identify and assemble a roadmap development team comprising key stakeholders for the development of the DSS to be embedded in the target city. To protect, support, and implement the solution, the team must consist of actors directly engaged in solution design and city actors (e.g., government, citizens, and social groups) who accept and utilize it in their lives. The team then articulates a long-term future DSS vision, the main future configuration of the target DSS. The generated vision ensures understanding of the role of the DSS in realizing the desirable goal and purpose of developing the roadmap.

<u>Phase 2: Identification of future needs</u>

This phase extracts future needs (FNs) that reflect the lifestyles of citizens in smart cities in the future, which constitutes the vision established in Phase 1. FNs refer to the future lifestyles desired by the citizens of the city that will be realized by the implementation of DSS. These are not only lifestyles that represent how current urban "problems" are handled, but also include lifestyles with improved well-being that will amplify the quality of life of the citizens. FNs are extracted and listed mainly through visionary workshops and questionnaires with citizens living in the target city.

Phase 3: Service concept generation

The development team generates a service concept that is offered by the DSS to fulfil the FNs extracted in Phase 2. Here, services are a bundle of functions provided through DSS, which are realized by the integration of the physical products, data, digital technologies, urban resources, and networks possessed by relevant stakeholders.

Phase 4: Prioritization of service concepts

As mentioned in one of the requirements of the DSS roadmapping, the development of various services proceeds simultaneously in a large-scale project such as smart city development. Therefore, it is necessary to support decision-making on priorities for the development of the derived SCs. Therefore, this phase prioritizes the development of each SC from the perspective of both the vision and the technical seeds that have been developed.

In the vision-driven prioritization, priority is calculated using the FN-SC linkage grid constructed based on quality function deployment (Figure 2). First, the importance of each derived FN is set. Here, the FNs with high importance are those that are strongly related to the realization of future lifestyles in light of the established vision. The importance is set at three levels (High: 5, Medium: 3, Low: 1). Then, the contribution of each SC to the realization of each FN is evaluated at three levels (◎: 5, ○: 3, △: 1). Then, the product of the importance of the FN and the contribution of the SC is summed up for each SC, and the development priority $VP_{SCi} (i = 1, \dots, n)$ of each SC is calculated.

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		Importance	Service concepts					
			SC1	SC2	SC3	SC4	SC5	SC6
Future needs	FN1	H	○	△				
	FN2	H			◎			
	FN3	M				△		
	FN4	L			○	○		
	FN5	M					○	◎
Priority of SCs			15	5	28	18	9	15

Figure 2. FN-SC linkage grid.

Second, in the seeds-driven prioritization, the degree of compatibility between those seeds and each SC is set as the development priority $SP_{SCi}(i = 1, \ldots, n)$ of the seeds in consideration of the resources possessed by the stakeholders who constitute the development team. The degree of compatibility is evaluated on a 5-point scale from "very compatible: 5" to "difficult with the current seeds: 1".

Then, based on the above two prioritization results, the development priority of each SC is evaluated from the two axes of vision and seeds. Here, each SC is placed on the SC priority matrix (Figure 3) to visualize the trade-off between vision-driven and seeds-driven priorities and to support decision-making in the development priority evaluation. This matrix is a two-dimensional map with VP_{SCi} on the horizontal axis and SP_{SCi} on the vertical axis and is classified into the following four areas. Note that VP_{SCi} uses standardized values to unify the value scale. Each quadrant is divided around the point of the average value of SP_{SCi} on the horizontal axis and 0 on the vertical axis.

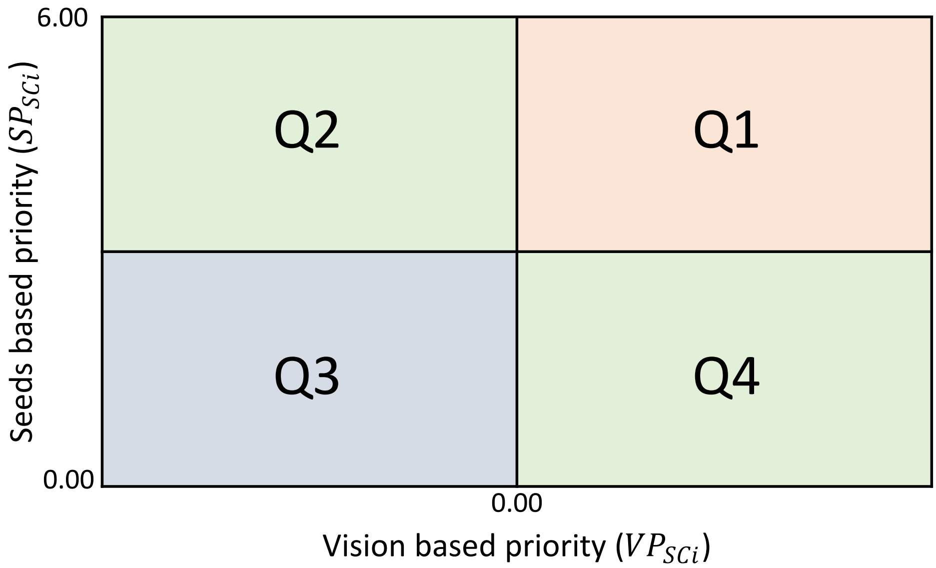

Figure 3. SC priority matrix.

Phase 5: Roadmap development

Phase 5 develops a roadmap for DSS design and implementation based on SC priorities defined in Phase 4. This study affords a DSS development roadmap format (Figure 4) to graphically design a strategy for future vision. This format consists of social, digital, and physical domains that represent the components of a DSS development strategy.

In this phase, a physical and digital domain roadmap was first developed. As the first step, an ordinal order of service development is arrayed in the service layer based on the result of prioritization in Phase 4. Subsequently, the physical product, digital system, data, and urban resources necessary to realize the functions are identified and arranged in each layer. These elements are extracted by sharing and integrating the knowledge of each stakeholder, including the development team.

In addition, if only the technological aspect of DSS development is emphasized, DSS implementation would conflict with contemporary social norms and practices (e.g., contradiction with governmental policies, impediments to citizens' social activities, and contradiction to data use) because of the lack of consideration of the social aspect of the target city. Therefore, these barriers are anticipated to inhibit successful design and integration of DSS into the city. To identify these barriers, it is preferable to exchange knowledge from the actual urban context, particularly from the government and citizens in the development team. Subsequently, a social domain roadmap is developed by identifying institutional/socio-cultural/network activities to deal with the identified barriers. The activities are then arranged in each layer.

Finally, the overall DSS development strategy is described by integrating the social, digital and physical domain roadmap.

Service concept		Idea of functions provided to realize the future needs of citizens
Social	**Institutions**	Activities to establish rules, norms, policy and regulations to implement services to the city properly
	Socio-culture	Activities to promote the use of the developed service in the city (Service experience events, PR, etc.)
	Network	Networking activities to integrate resources for service configuration
Digital	**Data**	Data that is acquired through the physical product and serves as a resource to realize the functions of service
	Digital systems	Technical systems that support the realization of functions in the backyard, invisible to citizens as physical entities
Physical	**Physical products**	Physical product that serves as a medium for service delivery and data acquisition
	Human resources	Organizational and human resources needed to provide services
	Urban resources	City-owned infrastructure required to provide services (buildings, facilities, utilities, physical infrastructure, natural environment, etc.)

Figure 4. Suggested roadmap layer for DSS development in cities.

Conclusion and future work

This study developed a framework of roadmaping for DSS that guides the strategic design of a DSS in smart cities. Practitioners of smart city initiatives and designers of DSS can collaborate with stakeholders to co-design the future vision they are aiming for and the transition trajectory toward that vision by developing a roadmap in accordance with this framework. Moreover, the proposed roadmap format facilitates consensus in building and sharing of strategies among stakeholders by graphically representing the elements and their relationships to be considered. Furthermore, the suggested framework can not only develop a roadmap but also adjust the initially formulated strategy by monitoring the derived milestones against the subsequent social environment and progress of the DSS.

Nevertheless, further research is required to address the following issues. First, the proposed roadmapping framework lacks theoretical validity because it was constructed based on a first brief literature review of smart city. Therefore, it is pivotal to elaborate the relationship between smart cities and DSS through literature review in each field to define more valid requirements for DSS strategic planning in smart cities. Second, this framework is merely conceptual and does not include a practical approach for practitioners to apply the concept to actual activities. The development of techniques and designing tools to implement each phase of the framework is necessary to assist roadmapping by engaging diverse stakeholders. Third, the utility and effectiveness of the proposed framework should be verified by applying it to actual DSS development after addressing the aforementioned issue. Because the actual development and implementation of DSS is a lengthy undertaking, it is anticipated that during the project the needs of citizens and the surrounding social situation would change.

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