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A Risk Management Model for Sustainable Smart City

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Abstract

A smart city is a concept that includes 'digital city' or 'connected cities' and means city composition using Information & Communication Technology. Government is actively using smarter management to solve various problems related to transportation, communication, security, health, quality of life, and so on as cities become more complicated and larger. It is explained that a smart city is developed through such management. The types of risks that occur in a smart city vary widely in terms of resilience and sustainability. In addition, the risks that occur in a smart city are varied and complicated depending on the conditions, circumstances, time, and so on of the smart city. Therefore, this study categorizes the risks that may occur in a smart city and proposes a smart city risk management model to prevent the risks from occurring in advance and to minimize the effect of the risk if a risk occurs in the smart city. First, the proposed risk management model classifies the risks that can affect the smart city into external risks and internal risks according to location, controllable risks, and uncontrollable risks according to controllability. Second, the proposed model includes measures to secure the resilience and sustainability of the smart city through risk prevention strategies and risk mitigation strategies.

Keywords*: Smart city, risk, resilience, sustainability, categorization, risk management model*

1. Introduction

A smart city is naturally becoming the center of culture and science as Korea goes beyond the quantitative economic growth stage and people's demands for quality of life become stronger. People's living environment is not a mere improvement through technology, but requires smarter, more environmentally-friendly elements, and evolves toward meeting complex requirements, requiring smarter management. The government is actively participating in the construction of a smart city to achieve the expectations of the people's needs effectively.

As cities become larger and more complex, management items such as sanitation, traffic, and healthcare are faced with various difficulties. The government is interested in 'smarter management' in order to effectively solve these problems in the city and to create an efficient city. Through this management, it is possible to express a developing city as 'Smart City' [1].

A smart city is defined by various concepts and is described as a concept that includes 'digital city' or 'connected cities'. A smart city is a conceptual city development model and means city construction based on Information & Communication Technology (ICT) [2]. Chris Rouland [3] defined the smart city as “Like a smart grid or smart automobile, a smart city implements modern information and communication technologies to improve the quality and performance of municipal services, while also reducing costs for its

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citizens.". U.S. Department of Homeland Security [4] defined it as "Urban centers that integrate cyber-physical technologies and infrastructure to create environmental and economic efficiency while improving the overall quality of life." and explained the role of smart city as "A smart city gathers data from smart devices and sensors embedded in its roadways, power grids, buildings, and other assets. It shares that data via a smart communications system that is typically a combination of wired and wireless. It then uses smart software to create valuable information and digitally enhanced services.". Arafah & Winarso [5] defined the concept of smart city as "A city that utilizes ICT to increase citizen's awareness, intelligence, wellbeing as well as community participation in facing pressures, shocks, and hazards in order to be able to survive, adapt, be tough, and able to transform, in order to that the community achieve a higher quality of life and environment, which is sustainable in facing the future era of uncertainties." and explained that the concept evolves from 'smart city as digital city' in 2000 to 'smart city as socially inclusive city' in 2005 and 'smart city as city with high quality of life' in 2010.

Wikipedia [6] defined the smart city as "It is an urban area that uses different types of electronic data collection sensors to supply information which is used to manage assets and resources efficiently. This includes data collected from citizens, devices, and assets that are processed and analyzed to monitor and manage traffic and transportation systems, power plants, water supply networks, waste management, law enforcement, information systems, schools, libraries, hospitals, and other community services".

To be recognized as a smart city, it must be associated with at least five of the eight parameters (smart energy, smart building, smart mobility, smart healthcare, smart infrastructure, smart technology, smart governance and smart education) [4].

Most studies on the risks of the smart city so far focus on security risks [1] [3] [4]. However, the risk factors affecting smart cities are very diverse and the consequences of the risks arising from the situation of smart cities are very different. Therefore, this study suggests a smart city risk management model that effectively responds to various risk factors that occur in the smart city in terms of resilience and sustainability.

In Section 1 of this study, the concept of smart city and the purpose of the study are explained. In Section 2, we describe the risk factors that occur in the smart city. In Section 3, we present a new risk management model that can effectively control the risks that occur in the smart city. Finally, Section 4 presents conclusions and future work.

2. Risk Factors of Smart City

Smart cities have a wide variety of components and a wide range of risks. Therefore, this study considers the risk factors of a smart city in terms of sustainability as described above. In order for a smart city to be sustainable, it must be prevented before the risk occurs, and a strategy that minimizes the impact of the risk if a risk arises.

Sustainability of smart cities can be improved through risk prevention strategies that prevent risks from occurring and risk mitigation strategies that minimize the effects of risks when they occur. Risk prevention strategies are a way to eliminate the cause of a risk, and risk mitigation strategies are a way to minimize the impact of the risk. It is effective to conduct risk prevention strategies by identifying as many possible causes of risks as possible and incorporating them into business processes to manage them regularly and continuously. Risk mitigation strategies are a strategy that is dealt with when a risk occurs in a smart city, so it is necessary to identify the most influential risk among those that occur. Therefore, a priority method is needed to find the most influential risk among the various risks, and this study focuses on an effective way to find the priority of the risk. This study also includes a measure to quantify the qualitative elements of risk.

Lacinak and Ristvej [7] presented 9 elements of the system that make up smart city (Smart Transport, Smart Energy, Smart Technology, Smart Living, Smart Environment, Smart Citizens and Education, Smart Economy, Smart Government, and Safe City).

McClellan *et al.*, [8] defined the area of the smart city as Tab. 1, respectively.

Table 1. Smart City's Part and Contents

Smart city's part	Contents
Technology and Architecture	-Smart grid -Internet of Things -Cloud
Transportation considerations	-Transportation electrification -Smart transportation systems -Reconfigurable computing for smart vehicles
Infrastructure and Environment	-Smart buildings and grid distribution management -Smart city lighting -Smart water solutions -Technology-enhanced infrastructure

Tab. 1, presented by McClellan *et al.*, [8] consists of smart city as Technology and Architecture, Transportation, and Infrastructure and Environment, and provides concrete details according to the constituent areas.

U.S. Department of Homeland Security [4] categorized smart city as Transportation systems sector, Electricity sector, and Water and wastewater systems sector. Because this study is described from the viewpoint of Smart city infrastructure, Transportation, Electricity, and Water are suggested as components of smart city.

Angelidou *et al.*, [9] defined risk factors and suggested mitigation strategies considering the environmental aspects of possible risks in smart cities.

This study presents the risk factors of smart city as shown in the following Tab. 2 by referring to the study of U.S. Department of Homeland Security [4], Lacinak & Ristvej [7], McClellan *et al.*, [8], and Angelidou *et al.*, [9].

Table 2. Risk Classification in a Smart City

Components	Risks
Smart Transport	-Traffic regulating technology -Transportation electrification -Smart transportation system (autonomous vehicle system malfunction, positive train control system failures, intelligent transportation system disruption, vehicle-to-vehicle and vehicle-to-infrastructure, widespread malfunction of automation systems) -Smart parking allocation -Reconfigurable computing for smart vehicle
Smart Energy	-Smart building and grid distribution management -Smart city lighting -Smart grid (smart power-generation plant disruption, smart distribution, and transmission manipulation)
Smart Technology	-Telecommunication -Internet of Things -Cloud -Security (physical and cyber security, information security)
Smart Living	-Healthcare -Sanitation
Smart Environment	-Smart recycling

	-Smart water solution (smart water-treatment facility disruption, smart water distribution system disruption, smart water-storage facility infiltration) -Smart grid (advanced metering infrastructure) -Technology-enhanced infrastructure -High traffic density -High amount of waste -Increasing air pollution -Increasing energy consumption/sinking resources -Loss of biodiversity and natural habitat -Sinking water resources
Smart Citizens and Education	-Cyber education -Cyber university -Information ethics
Smart Economy	-Smart payment -Starvation of funding -Smart insurance
Smart Government	-Electronic government -Electronic government procurement -Business continuity management (=continuity strategy)
Safe City	-Smart services (coordinated emergency planning) -Cyber criminals

Tab. 2 compares the factors that constitute the smart city by referring to the U.S. Department of Homeland Security [4] and McClellan *et al.*, [8], based on the nine components that make up the smart city proposed by Lacinak and Ristvej [7] and suggests new risk factors that may occur.

Smart Transport offers Traffic regulating technology, Transportation electrification, Smart transportation system, Smart parking allocation, and Reconfigurable computing for smart vehicles as risk factors. Smart Energy presents Smart building and grid distribution management, Smart city lighting, and Smart grid as risk factors. Smart Technology presents Telecommunication, Internet of Things, Cloud, and Security as risk factors. Smart Living presents Healthcare and Sanitation as risk factors. Smart Environment presents Smart recycling, Smart water solution, Smart grid, Technology-enhanced infrastructure, High traffic density, High amount of waste, Increasing air pollution, Increasing energy consumption/sinking resources, Loss of biodiversity and natural habitat, and Sinking water resources as risk factors. Smart Citizens and Education presents Cyber education, Cyber university, and Information ethics as risk factors. Smart Economy presents Smart payment, Starvation of funding, and Smart insurance as risk factors. Smart Government presents Electronic government, Electronic government procurement, and Business continuity management as risk factors. Finally, Safe City presents Smart services and Cyber criminals as risk factors.

3. Smart City Risk Management Model

From the perspective of resilience and sustainability, the types of risks that occur in smart city vary widely. In addition, the effect of the risk on the smart city varies depending on the conditions, circumstances, and time of the smart city.

Therefore, this section aims to categorize the risks that occur in the smart city, to prevent the risk from occurring in advance, and to suggest a smart city risk management model to minimize the impact of the risk if a risk arises. The proposed model classifies the risk of smart city as external risks and internal risks according to the place where it occurs and controllable risks and uncontrollable risks according to controllability. In

addition, the proposed model can be explained as shown in Fig. 1 below, ensuring the resilience and sustainability of smart city through risk prevention strategies and risk mitigation strategies.

To address the risks which occur in the smart city presented in Tab. 2 of Section 2, this study secures the sustainability of smart city using the smart city risk management model of Figure 1. Since the various risks that arise cannot be controlled simultaneously, the manager must determine the magnitude of the risk to respond to the risk. To measure risk, this paper uses the concept of Risk Management Action (RMA) proposed by Souza *et al.*, [10] and solve the fuzzy state information of risk by applying the Grey approach ([11] [12] [13]).

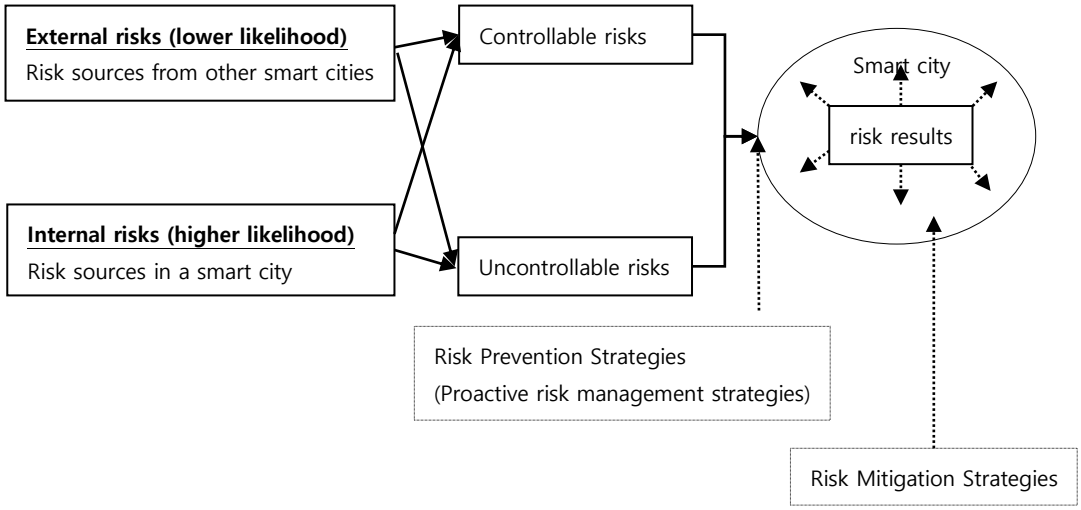

Figure 1. Smart City Risk Management Model

3.1. Risk Prevention Strategies

Smart city sustainability is greatest when it does not create a risk. Therefore, the risk prevention strategies of the smart city risk management model proposed in Fig. 1 is the stages of the prevention strategy. This step proceeds by finding the conditions to mitigate the risks presented in Tab. 2. Angelidou *et al.*, [9] proposed efficient transportation systems, compact city design, waste management and recycling, increasing green space, CO2 capture, reduction of atmospheric pollution, renewable sources, low energy buildings, increasing efficiency of devices and processes, developing animal and/or plant protection areas, and maximizing water use efficiency as a concrete strategy to mitigate the environmental risks of smart city. This study uses these mitigation strategies as risk prevention strategies. Fig. 2 shows risk prevention strategies used in this paper.

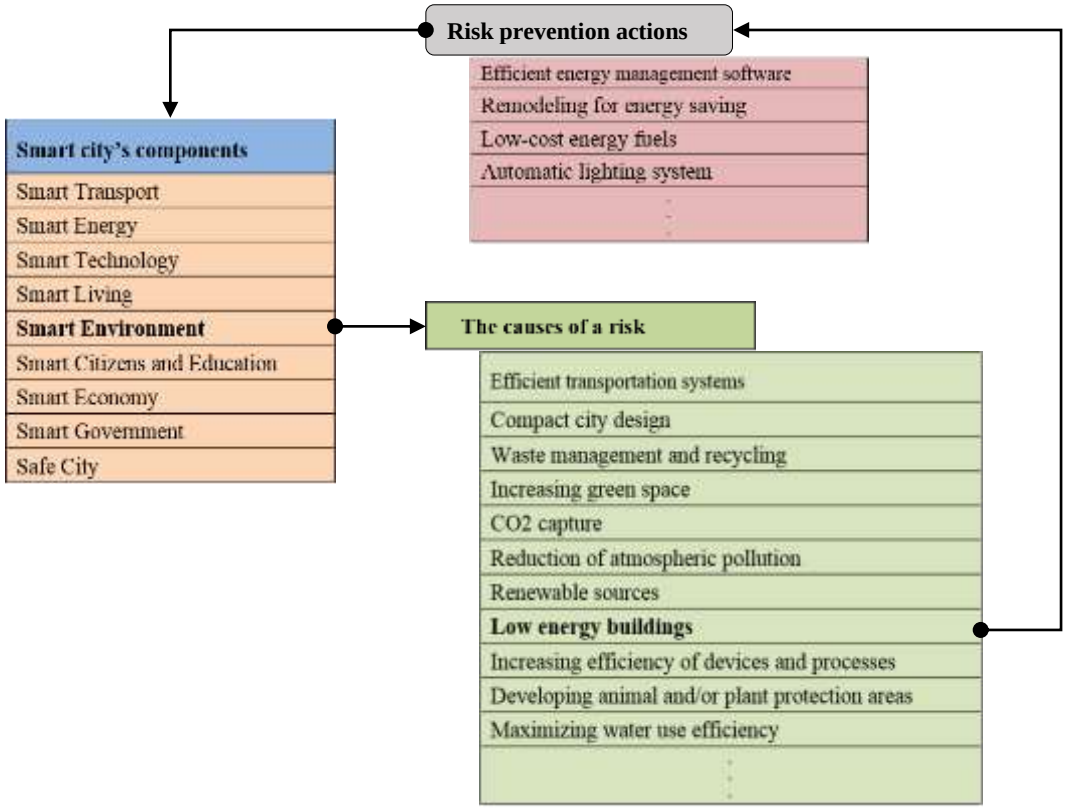

Figure 2. Risk Prevention Strategies

3.2. Risk Mitigation Strategies: Reflecting the Ambiguity of Risk

Since the risks that occur in the smart city include more qualitative characteristics than quantitative ones, the ambiguity of risk must be reflected. In other words, it is difficult to collect accurate information on the timing, frequency, and magnitude of the risk, and the effect of the risk on the smart city cannot be accurately measured. Therefore, this study is based on the Grey system theory ([11] [12] [13]) in order to prevent the risks occur in a smart city in advance by reflecting the uncertainty and inconsistency of this information.

Grey system theory is a method that considers fuzziness and flexibility conditions when considering insistent information in group decision making situations and is used to solve complexity and uncertainty problems in under discrete data and incomplete information. The Grey approach uses the Grey number of known and unknown information. The Grey number is represented by the boundaries of the Grey number between the known and the unknown, as illustrated in Fig. 3 [14].

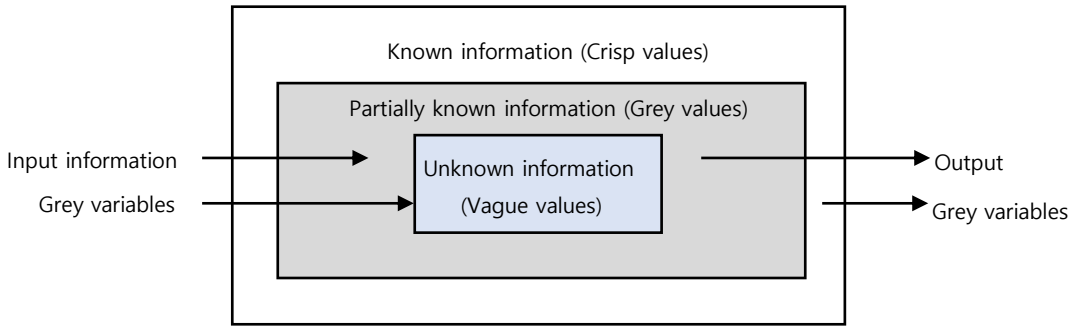

Figure 3. The Concept of Grey Theory [14] [15]

Britto *et al.*, [16] applied the Grey based ELECTRE approach for risk sorting. Li *et al.*, [15] applied a Grey based decision-making approach to the supplier selection problem. Memon *et al.*, [17] combined the Grey system theory with the uncertainty theory and applied it to the supplier selection problem. Baskaran *et al.*, [18] applied the sustainability evaluation of textile suppliers using the Grey approach.

3.3. Risk Mitigation Strategies: Measuring the Ambiguity of Risk

Souza *et al.*, [10] applied conditional-value-at-risk (CVaR) to measure the risk impact of a supply chain and calculated risk as Likelihood (of its occurrence) × Impact (of consequence) for risk assessment of the chain. To cope with the risk, this study created a Risk Management Action for the Impact and Likelihood as shown in the following Tab. 3 and assigned a value according to the magnitude of the risk. In Tab. 3, Impact is classified as Low, Medium, and High, and Likelihood (Frequency) is classified as Low, Medium, and High.

Table 3. Risk Management Action

Impact	Risk Management Action		
High	5 Considerable management required	15 Must manage and monitor risks	25 Extensive management essential
Medium	3 Risks may be worth accepting with monitoring	9 Management effort worthwhile	15 Management effort required
Low	1 Document risks	3 Document and monitor risks	5 Manage and monitor risks
	Low	Medium	High
	Likelihood		

In Tab. 3, the Risk Management Action is divided into nine areas by Impact and Likelihood, and each area is represented by a quantitative score. If a risk occurs in smart city, the risk value is assigned by Risk Management Action. However, the classification of Impact and Likelihood is so simple as Low, Medium, and High that it is difficult to grasp the effects of the risks in smart city at various levels. Also, there is a problem that the Risk Management Action is given as a score considering the Impact and Likelihood,

and there is not enough objective and rational basis to give this score. Therefore, we need an objective and reasonable method to further subdivide the classification of Impact and Likelihood and to score the Risk Management Action.

When a risk occurs in a smart city, various methods can be used to prioritize the risk by presenting objective and reliable quantitative measures of the risk, this study uses Impact and Likelihood of risk. If the classification of Impact and Likelihood of the risks encountered is too simple, it does not give a distinctive result between the risks encountered. On the other hand, if the classification of Impact and Likelihood is too subdivided, the linkage between the risks that occur is not affected and gives a very different result that all the risks are independent and can be erroneously broken. Therefore, the classification of Impact and Likelihood of risk requires a process of creating a reasonable level of classification by gathering the opinions of experts who are familiar with the smart city that should be managed. In other words, many elements with qualitative characteristics mean that, rather than using only tools or algorithms, collecting diverse opinions of people with expert knowledge in the field and incorporating them into the research process can give much more accurate results.

Therefore, this study is used in conjunction with the Grey approach described in Section 3.2 to present the Risk Management Action values in Table 3 by clear and objective criteria.

As described earlier, the risks that arise in smart cities are of a qualitative nature, which leads to unreliable results when the criteria are ambiguous. If the results are used to minimize the impact of a risk in a smart city, it can be a critical hit in a smart city. Therefore, it is very important to evaluate the qualitative characteristics of risks in smart city as objective and reliable results. This study applies Section 3.2 and 3.3's Grey approach and Risk Management Action to apply into risk mitigation strategies and then converts subjective qualitative attributes to objective and reliable quantitative measures.

4. Conclusions and Future Research

In the era of the 4th industrial revolution, the importance of information and communication technology is getting bigger and it is developing into a smart city that closely connects with information and communication technology. These activities require innovation of existing systems and processes, which can be expected to have a large effect but increase the risk. Existing studies on smart city mainly focus on the security of the smart city. However, if the area of interest in smart city is geared only to the security of information and communications technology perspectives, key requirements to improve the quality of life and optimize the productivity of people using smart city may not be met as expected.

This study proposed a smart city risk management model that classifies various risks occurring in smart city, responds efficiently, strengthens the resilience of smart city, and improves sustainability. Smart city can be limited to a virtual network space from the viewpoint of information and communication technology. However, since it is a physical space in which people live and perform various activities such as economic activity, it is impractical and undesirable to study only in a specific area.

Therefore, since smart city has various risk factors, this study suggested a risk management model to cope with these risk factors to ensure the resilience and sustainability of smart city. This study defined the external risks if they come from the outside of the smart city and the internal risks if they occur in the smart city. Also, the risks are defined as controllable risks that can be controlled and uncontrollable risks that are difficult to control.

The risks associated with smart city should be eliminated before the risk occurs, so there is no impact on smart city. This study defined risk prevention strategies as

establishing effective preventive policies before risks occur. If a risk occurs despite the precautionary policy to prevent the risk from occurring, the impact of the resulting risk must be minimized to ensure the resilience and sustainability of the smart city. Also, this paper defined the policy that minimizes the impact of the risk as risk mitigation strategies.

This study sought to eliminate or minimize the risks associated with smart city based on the risks and strategies defined above. The proposed model adopted the Grey approach to reflect the ambiguity of the risk and uses the concept of Risk Management Action to calculate the risk size and prioritize it.

However, this study suggested a smart city risk management model that can effectively cope with various risk factors occurring in smart city, but this model cannot be applied to actual environment. Therefore, future work will present quantitative evaluation factors for evaluating the proposed smart city risk management model and verify the effectiveness of the proposed model through the evaluation results. The quantitative evaluation factors presented are arranged according to the Risk Management Action based on the risk classifications shown in Tab. 2 above and the ambiguous relationship between the risks occurring is quantified by applying the Grey approach.

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