International Journal of Internet, Broadcasting and Communication Vol.14 No.1 152-161 (2022)
http://dx.doi.org/10.7236/IJIBC.2022.14.1.152

IJIBC 22-1-19

On the Supplementary Study on DSM-Based Interface Requirements through Analysis of the Operation Scenario of the Urban Subway Logistics System

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Abstract

Recently, it is recognized as a high-cost and inefficient logistics system that increases traffic congestion and environmental problems due to an increase in traffic volume due to the activation of the online market. In order to solve inefficient problems such as unavoidable traffic congestion and environmental problems caused by the increase in traffic volume, it is necessary to develop a freight transport system technology using the existing urban railway infrastructure and freight-only urban railway. The urban subway logistics system is a logistics system that requires a combination of various technologies to solve the nationwide demand for urban logistics and road traffic problems. This paper recognized the existing traffic congestion and environmental pollution of road traffic as problems, and supplemented the contact point requirements presented above by identifying the sub-systems constituting the target system and supplementary points for each part-level contact point. In this study, as a complex system operated for one purpose by grafting various technologies, a plan is required to secure the reliability and safety of operation from various viewpoints. The results of this study can contribute to the initial configuration and basic data to solve the interface bottleneck of the urban subway logistics system to be promoted in the future.

Keywords: *Urban Railway Logistics, City Freight Transport, Operation Scenario, Systems Interface, Design Structure Matrix (DSM)*

1. Introduction

1.1 Research Background and Necessity

Based on four strategies in 2016: fostering high value-added logistics industries, upgrading and efficient logistics facilities, establishing a sound market order, and expanding logistics industry jobs and future new growth engines, the Korean government presented a logistics industry vision through 2016-2025. This includes the contents of preparing a plan to secure life-friendly urban logistics facilities through the analysis of the current status and problems of logistics facilities in the city. In addition, the 1st Railway Logistics Industry Promotion Plan and the 3rd Logistics Facility Development Comprehensive Plan suggest urban railway utilization strategies to improve the urban logistics environment, such as establishing a terminal delivery system based on urban railway history. In order to meet these government policies, it is necessary to

Manuscript Received: December. 19, 2021 / Revised: December. 25, 2021 / Accepted: December. 28, 2021
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change the logistics system in the metropolitan area, which accounts for a significant portion of national and social costs such as serious bottlenecks entering the city and environmental problems through road congestion, from road-oriented transport to relatively eco-friendly railway facilities. Existing urban freight transportation was mainly carried out by freight trucks centered on roads, and accordingly, freight transport was carried out by individual freight trucks from outside the city to the city center. However, as the volume of goods increased, truck operations increased, causing traffic congestion and environmental problems, and accordingly, it is becoming recognized as a high-cost inefficient logistics system in which social costs increase together. In order to improve inefficient problems such as inevitable traffic congestion and environmental problems arising from the increase in volume, it is necessary to develop cargo transportation system technology using the existing urban railway infrastructure and cargo-only urban railroads. Urban logistics technology using urban railway facilities uses underground spaces such as urban railway infrastructure base and urban station built in the city to improve investment efficiency and continuously increase urban freight based on this.

1.2 Previous Studies and Analysis of Domestic and Foreign Urban Railway Logistics Infrastructure Operation Cases

In this section, prior research and analysis of domestic and foreign urban railway cargo operation cases will be conducted before implementing the existing urban railway infrastructure and a freight transport system using freight-only urban railways. First, in terms of environmental problems caused by inevitable increase in traffic volume due to increased traffic volume, a comparative study of air pollutants and greenhouse gas emissions was conducted [1]. Recognizing the movement of road-centered transportation to eco-friendly transportation systems such as railroads, this study calculated, compared, and reviewed quantitative data on eco-friendliness of railroads. As a result of the study, it was confirmed that the emission of air pollutants per unit transport of road transport was 7 to 15 times higher than that of railroads except for SO2. In addition, in the case of greenhouse gases, it was confirmed that road transport emits about four times the level of greenhouse gases compared to rail transport. As such, this paper was conducted from a comparative point of view with railroad transport, but research to solve the problem of environmental pollution in road transport is being conducted from a convergent point of view in various fields such as logistics, distribution, machinery, and artificial intelligence. Although it was aware of social problems such as traffic congestion and environmental pollution in road transport, it is not possible to stop road transportation operated in various logistics and distribution fields at this point. Therefore, in order to increase the efficiency of transportation from the perspective of operation technology through the linkage between road transport and rail transport, a case study of cargo train operation technology through road transportation and rail transportation has been conducted [2, 3]. In this study, it was conducted to realize an efficient transportation operation system by introducing a new concept of cargo transportation and operation system, recognizing the problems of Korea's transportation operation system, which is concentrated on road transportation and traffic congestion. First, the government has established various systems to promote the transition of transportation by expanding the operation of eco-friendly transportation, but it was recognized that despite the government's efforts, the share of rail transportation is rather decreasing. The factors for this were found to be the inability to transport door to door and Just In Time, and the complicated procedure for transshipment and transportation, resulting in unnecessary time required for loading and waiting. Accordingly, the expansion and operation technology of the large 27-ton truck/trailer on flat car (TOFC) based piggyback transport method satisfying the vehicle limitations of existing railway facilities was proposed, and the necessity of conducting certification tests for technology and prototypes was suggested. In 2010, Japan's Sapporo City Transportation Bureau introduced a delivery and cargo transportation system using mobile carriers based on urban railways. In December 2011, France's Regie Autonomous des Transports Parisians (RATP) operated cargo transportation between passenger transportation using tanks that were suspended in the city. It operated six times a week, and operated a transport system that transports 17 tons of cargo for four weeks. In 2017, the Seoul Transportation Corporation of Korea collaborated with the Korea Railroad Technology Research Institute and C Logistics to conduct underground cargo transportation tests using urban railroads. This was performed for the purpose of deriving a schematic system operability by identifying constraints on infrastructure, idle spaces that can be used as moving routes and logistics spaces. In this case, it is possible to confirm the schematic process of the existing urban railway infrastructure and the logistics system based on urban railway vehicles. This section attempts to grasp the considerations related to this study from the perspective of the target system through the case of the urban subway logistics system performed in advance. The case was conducted for the purpose of deriving a schematic system operability by identifying constraints on infrastructure, idle spaces that can be used as cargo train movement routes, and logistics spaces. First, the schematic logistics system process was performed in the order of logistics terminals, urban railway vehicle bases, urban railway vehicles, underground stations, and customers. The logistics terminal classified cargo with a separate code among the cargo collected from the courier hub and loaded it into a rolltainer, which was shipped by 11 tons of vehicles. The process of collecting cargo from the courier hub. After a cargo vehicle containing a cargo with a separate code applied to the urban railway vehicle base entered, a rolltainer transshipment procedure from an 11-ton cargo vehicle to an urban railway vehicle was carried out using a forklift. Thereafter, the urban railway vehicle arrives at the subway station, and the personnel directly classified the cargo of the rolltainer by region. The cargo classification process was performed. The cargo classified as the following procedure was moved using a non-automatic conveyor, and then, it was loaded on an electric cart on the ground and delivered to the customer. In this case, practical operation plans for cargo transportation, unloading, and classification using urban railway vehicle bases, urban railway vehicles, and underground stations were reviewed, and the necessity of transitional work spaces such as cargo separation, loading, and loading by destination was derived. In addition, it was derived that the cargo rolltainer inside the urban railway vehicle moving from the vehicle base to the underground station can cause damage to the cargo in the transportation environment due to rapid and deceleration. Therefore, when transshipment of cargo rolltainers in urban railway vehicles, the necessity of allocating and binding cargo rolltainers linked to the order of return and access was recognized. The problem was that manpower had to directly perform the delivery process to customers through cargo classification, which could appear as a problem from an operational economic point of view when operating the system in the future. Through this case, it is possible to confirm a schematic process of an existing urban railway infrastructure and a logistics system based on an urban railway vehicle. In addition, when operating a system, it is possible to identify problems, limitations, and additional considerations that may occur at the target system and subsystem level.

1.3 Research Procedure

Figure 1 shows the Schematic research process. In the introduction to Section 1 of this paper, the need for an urban railway-based logistics system that can utilize the existing urban railway infrastructure was presented by recognizing the traffic congestion and environmental pollution of road transportation as problems. Prior research analysis was conducted from the perspective of road transport to railway transport, foreign cases of implementing logistics systems using existing urban railway infrastructure, and basic considerations for implementing urban subways presented in this paper were derived through domestic case analysis. Section 2 presents the operating scenarios necessary to implement the logistics infrastructure system for urban subways from the perspective of the entire system using the modeling support tool. In Section 3, operational scenario analysis was performed from the perspective of the entire system using Design Structure Matrix (DSM). Through this, problems and limitations that may occur when operating the system were identified, and interface requirements from a subsystem perspective were additionally derived. Section 4 summarizes the results of this and supplements the operating scenarios, procedures, and system interface requirements necessary for the operation of the urban subway logistics system. Section 5 evaluates the research results conducted in this paper and presents the direction of future tasks.

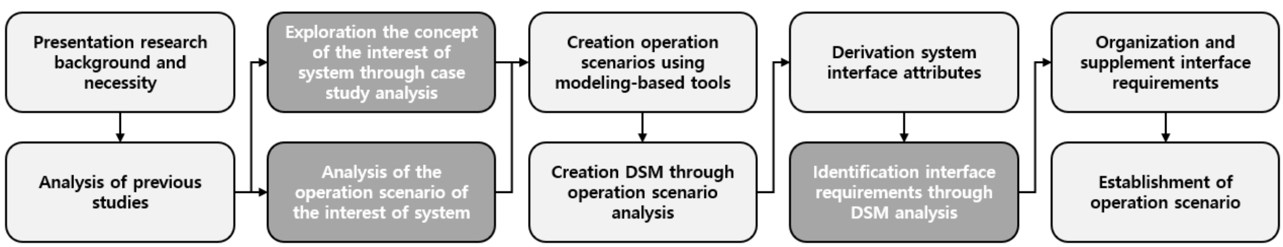

Figure 1. Schematic research procedure

2. Analysis of the Underground Railway Logistics System

The urban subway logistics system is a proposed logistics system that requires grafting of various technologies to solve the problems of urban logistics demand and road transportation, which have soared nationwide. First, considering the logistics demand in the city, it is important to select a vehicle base that can store cargo at Hub terminals and an urban station that can handle cargo within major urban areas. In addition, since cargo trains transport cargo between passenger train operations are operated, it is necessary to review and analyze the operation scheduling and signal system, identify logistics demand in the city, and review and analyze cargo trains through forecasting expected volume. Next, it is necessary to organize and manufacture standard containers appropriate for handling cargo according to the expected volume of cargo in the city center, and Automated Guided Vehicle (AGV) will be used to minimize personnel between departure space, cargo train, and arrival space. In this study, urban subways were also selected as target systems, and subjects and objects were selected as logistics spaces for cargo loading (including vehicle base and urban station cargo handling staff), horizontal transport devices, vertical transport devices (including barcodes for transportation data transmission), and servers for data management. Figure 2 shows the Shematic of urban railways logistics infrastructure.

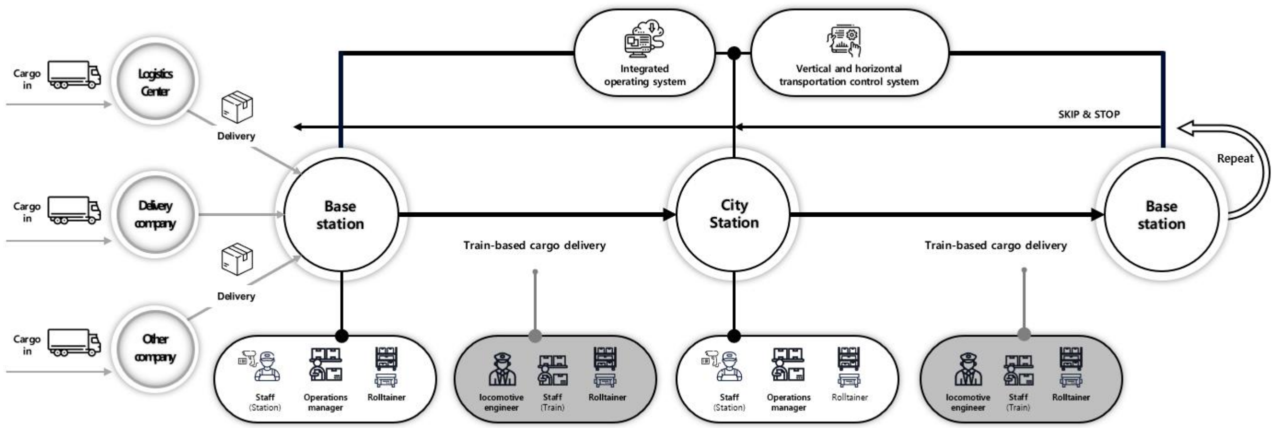

Figure 2. Schematic of urban railways logistics infrastructure

2.1 Classification of Subsystem Levels According to Operating Procedures

In this paper, in order to redefine the concept of an urban subway logistics system, classification at the subsystem level was performed according to each mission. The process of moving the standard cargo transport container fastened with AGV by cargo train in the vehicle base logistics space. In this case, the cargo transport standard container is received by the vehicle base operator and moved under the control of the control system. The conceptual diagram of AGV and cargo transport standard containers controlled by the control system. The AGV is located under the cargo transport standard container, fastened to the cargo transport standard container containing cargo by the vehicle base operator, and controlled by the control system. The cargo train transporting cargo, and The half of the AGV and cargo transport standard container that moves to the vertical transport device under the control of the control system after the cargo train arrives at the urban station platform. The cargo arriving in the urban history logistics space through the vertical transport device and The cargo arriving in the urban history logistics space. Interface requirements shall be reviewed through identification to modify the shape and determine the specifications of the sub-system and component of the target system.

2.2 Analysis and Modeling of the Operation Scenario of the Logistics System for Urban Subways

In this section, as an initial procedure for implementing the logistics infrastructure of urban subways, it is intended to present the operating scenario from the perspective of the entire system. The operating scenario was presented by dividing it into Subject, Objects 1-2 and State 1-2 and Activation. For example, "Scenario 1 - The cargo must be placed in the storage space of the vehicle base while being contained in a standard container for cargo transportation. Scenario 2. - The vehicle base operator scans the transport barcode of the standard cargo transport container using a hand scanner and performs the cargo warehousing procedure. Scenario 3. - The vehicle base operator classified the horizontal transport device under the cargo transport standard container from a descriptive point of view. The corresponding operating scenario can be expressed in detail according to the domain of each subsystem, but in this study, the operating scenario was analyzed from a schematic perspective as a study to establish the concept of the entire system. As an initial procedure, when the cargo arrives in the vehicle base logistics space in a standard container, the vehicle base operator places the horizontal transport device under the standard container and engages it with the standard container. Next, the transport information barcode of the standard container is scanned using a hand scanner. The scanned data is transmitted to the transfer device control system through a hand scanner, and the control system analyzes and records the transmitted data.

3. Identification Interface Requirements Based on Design Structure Matrix

3.1 Overview of Design Structure Matrix

Figure 3 shows DSM concept and schematic diagram. In this paper, DSM methodology was used to identify the interface requirements of the underground urban railway logistics system. In order to achieve conceptual design from design requirements, various methodologies such as DSM, Quality Function Deployment (QFD), Analytic Hierarchy Process (AHP), and Kano model analysis can be used. The DSM technique expresses the relationship between each component and is widely used as a system modeling tool that integrates the components [4]. The QFD technique is widely used in product design to reflect customer needs [5], and the Kano model analyzes the attributes of services into five categories: attractiveness, single-dimensional, essential, indifferent, and reversal [6]. Also, In a study on the design development of IoT smart mobility services for the transportation vulnerable in the digital transformation era, Lee et al. conducted a qualitative analysis based on QFD to understand the importance of user requirements [7]. AHP analysis is called an analytical stratification process and is used as a methodology for rational decision-making as one of the methods to support decision-making through multi-area evaluation criteria for many alternatives [8]. In this paper, DSM methodology was used to identify the interface requirements of the underground urban railway logistics system [9]. The DSM technique is an abbreviation for design structure matrix, a square n by n matrix, a method of expressing a system or project, and is also referred to as the dependency structure method, dependency source matrix, etc. [10]. The DSM technique has the advantage of being able to graphitize and express a matrix, making it easy to expand, and helping intuitive understanding. The system elements of the DSM are displayed in the first row and left column of the matrix, and may represent product components, organizational subordinates, or project activities. After listing the elements of the system in this way, the relationship between each other can be expressed inside the system. There is a binary DSM that can be expressed in a figure with '1' or '0' divided into a correlation or non-existence, and there is a nominal DSM that can numerically express the degree of relationship between each element.

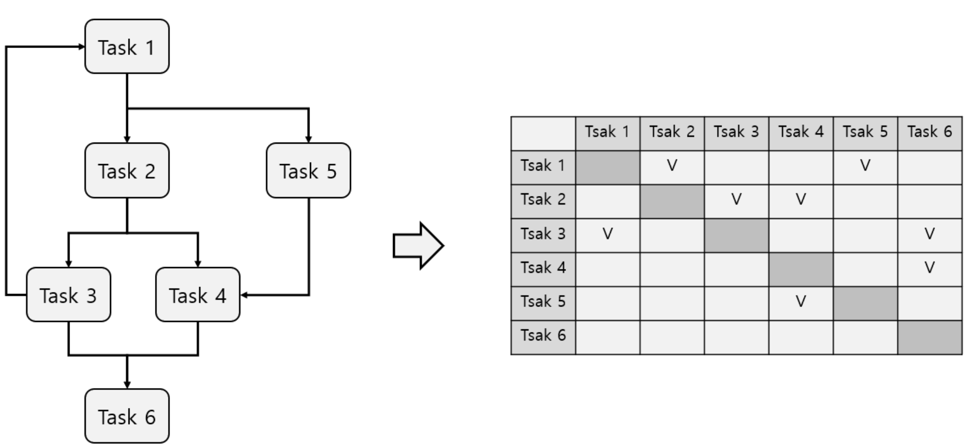

Figure 3. DSM concept and schematic diagram

3.2 Design Structure Matrix Analysis through Operation Scenario Analysis

It consisted of subsystems and components that were sequentially related in the process of arrival from the time the cargo was received into the vehicle base logistics space to the historical logistics space in the city center, and 14 subsystems and components constituting the target system were identified. In this paper, in the operating scenario, all conditions with interfaces for each subsystem and component are expressed as one interface, but a method of distinguishing the degree of each interface is needed. For example, there is a problem with how many vehicle base workers should be deployed because there is no expected volume of cargo in the vehicle base. To solve this problem, it is necessary to predict idle spaces and analyze expected volume of vehicle base logistics spaces that can be used in practice. Second, there is a problem with how to receive standard cargo transport containers and transmit them to the control system in a scenario where a vehicle base worker at a vehicle base receives cargo. AGV – Freight Transport Standard Container – Freight Train Binding Device – At the interface of the freight train, AGV is fastened to the freight standard container, and AGV itself is bound to the freight train binding device. In addition, it is also necessary to specify the interface on how to configure the binding method. When the cargo transport standard container containing cargo is fastened to the AGV and placed on the cargo train, physical interference with the door may occur due to the difference in the height of the cargo train. In the recovery operation scenario, it is carried out for the purpose of recovering the used AGV and cargo transport standard containers, and measures are needed to efficiently perform them. It is also necessary to supplement the operating scenario of AGV's power supply method. For example, AGVs that have completed the movement of standard cargo transport containers are placed in logistics spaces within urban railway stations and stored until the recovery operation scenario, but there is no standard for this, so there is a concern about AGV discharge. In the analysis of abnormal operation scenarios, concerns about damage can be cited depending on the operating environment of the freight train in the process of transporting standard cargo containers containing cargo, and corresponding measures should be taken. However, no standards have been established for how and what measures cargo train workers will take to meet the standards. Therefore, in order to solve this problem, it is necessary to organize a manual for responding to emergency situations and taking measures through analysis and review of abnormal operation scenarios.

4. Suggestion System Specifications and Improvement Plans through Interface Requirements Identification

By analyzing the operating scenario of the urban subway system and identifying DSM-based interface requirements, the previously proposed system specifications and interface requirements were supplemented. First, matters requiring supplementation from various perspectives were identified for each interface. Through DSM analysis of the recovery operation scenario, the problem of standard cargo transport containers and AGV recovery methods was derived. In this paper, in relation to the improvement plan through DSM-based requirement identification, it is intended to present a plan for the operation scenario of recovering AGV and cargo transport standard containers. The standard cargo transport containers and AGVs that have completed cargo transfer are placed in the urban railway station logistics space. Although there is a procedure for performing recovery, the need for efficient operation for AGV and cargo transport standard container recovery procedures was derived because there is a limitation in the placement of workers in vehicle base logistics space and urban railway station to perform recovery. As a plan for this, a method of configuring a standard cargo transport container in a foldable manner and recovering it by AGV is proposed.

Figure 4(a) shows Conceptual diagram of Vertical transfer system and Also, Figure 4(b) shows AGV / Standard rolltainer. As a result of seeking advice from a rolltainer expert, about four standard cargo transport containers can be recovered at once when manufacturing standard cargo transport containers in a foldable manner. However, since the base of the cargo transport standard container changes, additional improvement measures for the shape of AGV are needed using 3D CAD from a structural point of view to facilitate fastening.

(a) Vertical transfer system

(b) Automated Guided Vehicle and Rolltainer

Figure 4. Conceptual diagram of Vertical transfer system & AGV / Standard rolltainer

This is the time when research on urban subway logistics systems is being conducted for the purpose of building a logistics system using trains operating in the city center, and basic procedures and operation scenarios have been established to this end. However, there are restrictions on the operation of passenger trains and cargo trains without interference. In other words, it is necessary to analyze the scheduling that can operate freight trains between passenger trains and passenger trains. This scheduling review is a key factor necessary to ensure the operational stability of freight trains and passenger trains. Interface requirements for this requirements include railway control system and cargo control system, platform screen door (PSD) operation, and response manuals to enable cargo train drivers to take action in the event of abnormal scenarios. The scheduling review process for the mixed operation of passenger trains and freight trains. In the future, it is necessary to secure driving safety through scheduling simulation review and analysis.

5. Deduction the Specifications of the Underground Urban Railway Logistics Infrastructure System

Based on four strategies in 2016: fostering high value-added logistics industries, upgrading and efficient logistics facilities, establishing a sound market order, and expanding logistics industry jobs and future new growth engines, the Korea government presented a logistics industry vision through 2016-2025. This includes the contents of preparing a plan to secure life-friendly urban logistics facilities through the analysis of the current status and problems of logistics facilities in the city. Existing urban freight transportation was mainly carried out by freight trucks centered on roads, and accordingly, freight transport was carried out by individual freight trucks from outside the city to the city center. However, as the volume of goods increased, truck operations increased, causing traffic congestion and environmental problems, and accordingly, it is becoming recognized as a high-cost inefficient logistics system in which social costs increase together. In order to improve inefficient problems such as inevitable traffic congestion and environmental problems arising from the increase in volume, it is necessary to develop cargo transportation system technology using the existing urban railway infrastructure and cargo-only urban railroads. The urban subway logistics system is a proposed logistics system that requires grafting of various technologies to solve the problems of urban logistics demand and road transportation, which have soared nationwide. Recognizing the existing traffic congestion and environmental pollution of road transportation as problems, this paper presented the need for an urban railway-based logistics system capable of utilizing the existing urban railway infrastructure. Prior research analysis was conducted from the perspective of road transport to railway transport, foreign cases of implementing logistics systems using existing urban railway infrastructure, and basic considerations for implementing urban subways presented in this paper were derived through domestic case analysis. In addition, to present the operating scenarios necessary for implementing the logistics infrastructure system for urban subways from the perspective of the entire system. Operational scenario analysis was performed from the perspective of the entire system using DSM, and through this, problems and limitations that may occur when operating the system were identified, and interface requirements from the perspective of the subsystem were additionally derived. By summarizing the results, the operating scenarios and procedures and system interface requirements necessary for the operation of the logistics system for urban subways were supplemented. Specific research performance identified the requirements for supplementation for each interface at the subsystem and component level constituting the target system, and supplemented the previously presented interface requirements. This study requires a plan to secure operational reliability and safety from various perspectives as a fusion and complex system operated for one purpose by combining various technologies. The results of this study can contribute to the initial configuration and base data to resolve the interface bottleneck of the urban subway logistics system to be carried out in the future. The development of convergence and complex systems in the graft of ICT technology is self-evident, and it is considered that a methodology for identifying interface requirements between subsystems, components, and parts constituting the entire system is necessary.

Acknowledgement

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 21HCLP-C163194-01)

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