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On the Evaluation Criteria of Test Bed Based on Urban Logistics System Using Underground Space

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Abstract

The development of logistics technology due to the 4th Industrial Revolution and logistics 4.0 has changed the logistics environment from offline to online, and the growth of the online market has accelerated due to the recent increase in non-face-to-face delivery due to COVID-19. Such growth in the online market has expanded the logistics market for delivery, and contributes to creating an advanced logistics ecosystem as last mile services and logistics technologies begin to grow together. As traffic and environmental problems arise as a result, interest in transportation means of cargo increases, and changes to cargo electric vehicles and delivery cycles are being considered. However, since mass transportation of transportation focused on terminal delivery such as cargo electric vehicles and delivery cycles is limited in handling large quantities in urban areas, methods for efficiently transporting cargo while considering the environment are being devised. In order to solve such environmental problems and increase the efficiency of logistics delivery in urban areas, technologies using underground spaces based on existing urban railroads are being developed. In this study, a study was conducted on the establishment of evaluation criteria for selecting a test bed, which is a space for applying the system.

Keywords: *Underground Logistics, Urban Logistics, Logistics Delivery, Logistics Engineering, Warehouse Location*

1. Introduction

1.1 Background

The development of technology has led to the development of the online market, which has led to the activation of e-commerce [1]. With the Fourth Industrial Revolution, the era of logistics 4.0 began based on the Internet of Things, big data, climbing computers, and mobile-based systems [2]. Recently, the growth of the logistics market has been accelerating due to the increase in non-face-to-face delivery due to the pandemic

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[3]. The growth of the online market and the pandemic caused by COVID-19 have led to a surge in parcel delivery and increased logistics and transportation in the city center. However, as logistics and transportation in the city center increased, transportation problems and environmental problems emerged as social problems. Most of the existing urban logistics systems are delivered using fossil fuel-powered cargo trucks, and cargo transportation from the outskirts of the city to the city center is the main. The increase in cargo vehicles causes road traffic congestion, and social costs such as environmental problems such as air pollution and greenhouse gases caused by vehicle exhaust gases, traffic accidents, and road damage are incurred.

To solve various social problems, including environmental problems, several countries are developing eco-friendly transportation technologies and seeking ways to increase the efficiency of road flow. In Switzerland, a nationwide underground automatic logistics network is being built through the CST (Cargo Sous Terrain) project that transports cargo through underground logistics tunnels between major cities and distribution centers. In Europe, such as Sweden and Germany, an e-highway system has been developed that allows hybrid trucks to charge and drive batteries simultaneously by receiving power from power lines installed on the road through the pantograph, a current collector. In addition, a model for the dual application of Urban Metro (M-ULS)-based passenger commuting and underground logistics, and real-world simulations confirm that M-ULS systems can significantly reduce road cargo traffic and improve urban road service capacity [4].

Recently, research has been conducted on the logistics delivery system using existing urban railway facilities and underground space infrastructure existing in the city. The urban logistics system using urban railway facilities and underground spaces can contribute to reducing traffic and environmental problems that have emerged as logistics transportation problems and has the advantage of transporting a large amount of cargo at a designated time. In addition, it can contribute to providing services that can rapidly and stably handle and transport city cargo, which is constantly increasing as the market changes. Therefore, it is necessary to derive suitable test bed candidate stations to introduce a logistics delivery system using urban railway facilities and underground space infrastructure.

1.2 Previous Literature Review

Using the AHP (Analytic Hierarchy Process) method through the survey, the criteria for selecting the location of the logistics center were presented as cost factors, geographical factors, transportation factors, human factors, and policy factors by industry, and the relative importance of each factor was calculated [5]. Market, transportation, manpower, and social factors were presented as factors to consider in selecting the location of the distribution center, and weights for each factor were derived using AHP techniques [6]. In order to analyze the characteristics according to the location of the distribution center, the sales volume and the quantity of goods transported were set as dependent variables, and the quantity of goods transported, the economic accessibility, the shortest distance from the IC on the expressway, the annual processing performance, the sales volume, the transportation time, and the number of warehouse workers were set as independent variables to analyze the correlation between the factors [7]. The location factors of the distribution center were classified into core logistics functions, administrative support, economic feasibility, standardization/collaboration, and convenience. Through a survey on satisfaction and importance by location factors, it was confirmed that convenience factors such as convenience of using transportation networks, availability of simultaneous vehicles, and appropriateness of warehouse facilities also affect the location of logistics centers [8]. In order to select the location of the distribution center, the analysis was conducted using AHP techniques based on three evaluation factors: site conditions, usage demand, and environment/policy, and it was confirmed that importance was shown in order [9]. A method for calculating the location conditions of the distribution center was proposed that comprehensively considers three factors: transportation accessibility, ease of lease, and manpower availability [10].

By analyzing the case of AMAZON, the distribution of logistics warehouses and locations emphasized the delivery system of regions where small distribution centers deliver locally by trying to maximize market access [11]. To characterize the urban last mile e-commerce distribution strategy, we present an integrated framework that takes into account variables commonly addressed in urban logistics literature, such as the architecture and accessibility of urban last mile distribution networks [12]. It is proposed to use the AHP technique to select the location of efficient distribution centers, and distribution costs, traffic conditions, catering conditions, construction conditions, and rental costs were set as analysis factors for location selection [13]. The UTASTAR method was proposed as a method to determine the location of the distribution warehouse, and a case study suggested that the optimal warehouse location could be selected [14]. The integrated grey MCDM model was proposed as a method of determining the location of the warehouse, and the evaluation of the location was performed considering 12 criteria, and sensitivity analysis confirmed that the change in weight affects the ranking of the evaluation results [15]. To determine the location of the logistics warehouse, we propose a method through mathematical model configuration, optimization, and simulation methods, and conduct scenario studies on input data and model parameters [16]. Figure 1 shows a diagram of the problem definition. The absence of research that derives evaluation based on underground space through prior literature research is judged as a problem definition and a method to solve it is presented.

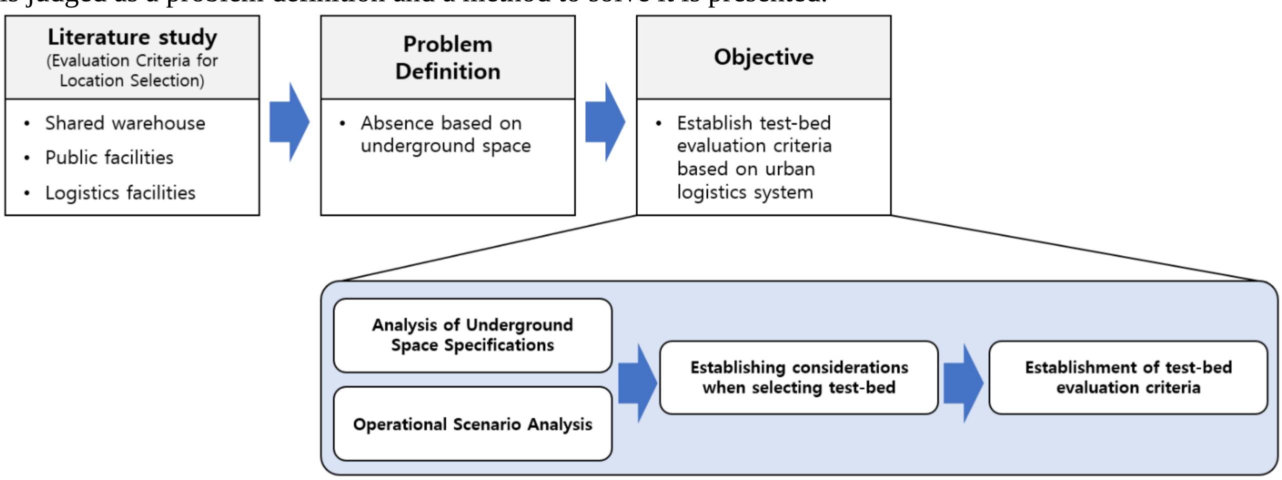

Figure 1. Problem Definition

1.3 Composition of this paper

In this study, the basic concept of urban logistics system using underground space is established, and evaluation criteria are established and presented for selecting test-bed candidate stations for the introduction of underground logistics delivery system. Figure 2 shows the research procedure and purpose. A logistics system using underground space is defined, an operation scenario is derived, and then considerations are derived when selecting a test bed based on previous studies. The final evaluation factor is determined through expert feedback on the derived considerations. The composition of this paper is as follows. In the following chapter 2, we establish the concept of urban logistics system using underground space. Chapter 3 presents the method of establishing test bed evaluation criteria based on urban logistics system using underground space and the factors of established evaluation criteria, and the last Chapter 4 summarizes the entire contents.

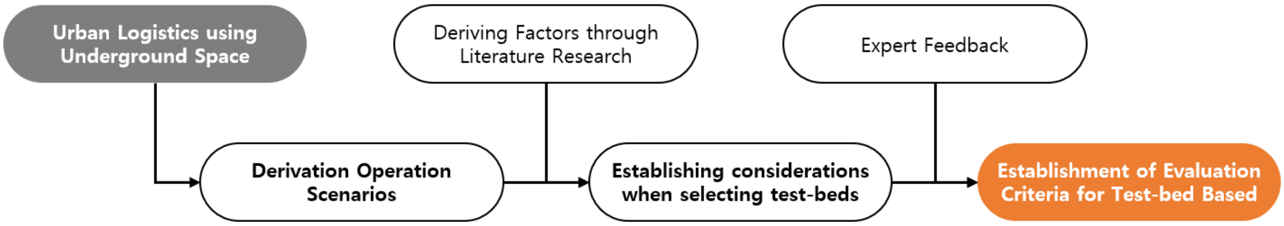

Figure 2. Research procedures and objectives

2. Related Work

2.1 Concept of Urban Logistics Test-bed Using Underground Space

The urban logistics system using underground space is a new concept that is not existing and aims to provide logistics services using the existing urban railway network and aims to connect cargo transportation to terminal delivery using underground space. Currently, freight transport in the city center is mainly based on road-based freight vehicles, but the urban logistics system using underground space operates a freight-only urban railway that moves through designated urban railway stations for transporting cargo. Therefore, there is a technical difference from the existing logistics system in that cargo is processed using the existing urban railway station and freight train. Using the urban logistics system using underground space, rapid transportation to designated urban railway stations will be possible through cargo-only urban railways. The logistics space in the joint logistics terminal built using the urban railway infrastructure is built based on the facility environment of the railway vehicle base. Figure 3 shows the concept and composition of the logistics space in the joint logistics terminal using the underground space.

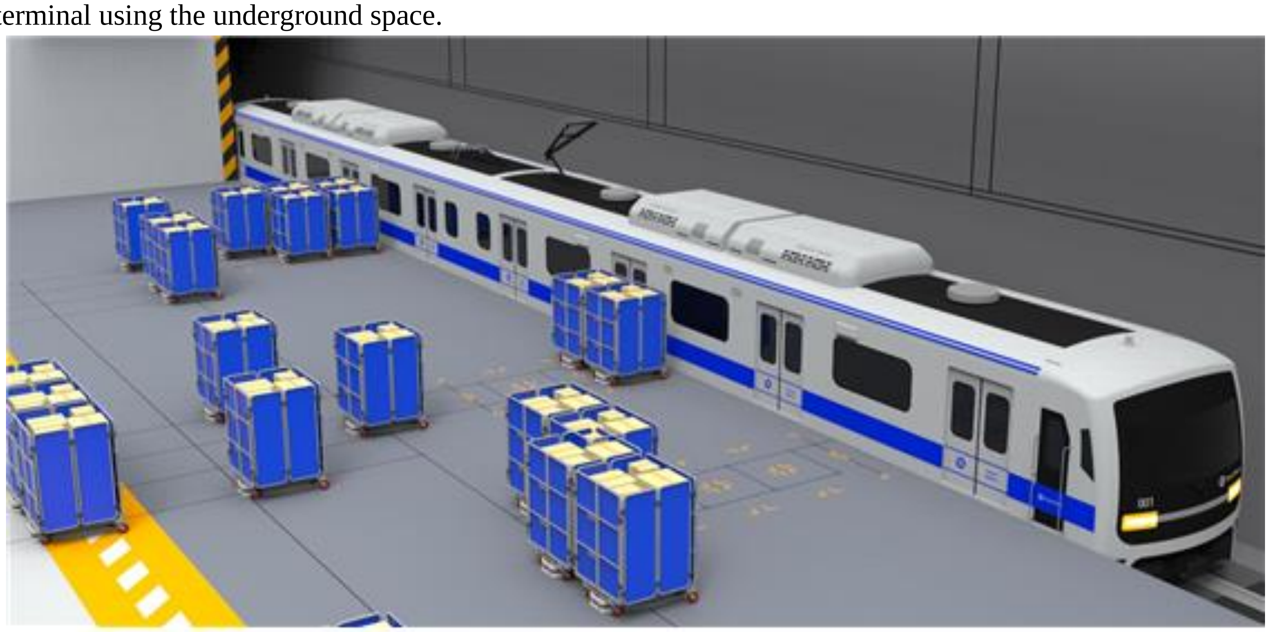

Figure 3. Logistics Space in Joint Logistics Terminal

2.2 Urban Logistics System Operation Scenarios Using Underground Space

Urban logistics systems utilizing underground spaces should be operated organically while technology development elements share information systems in real time for the smooth operation of the entire system. Therefore, it is necessary to select an appropriate urban railway station in the city center where all systems can operate normally for organic operation. Therefore, in this chapter, by deriving an operation scenario of an urban logistics system using an underground space, we will examine the areas to be considered in selecting the city railway station in the city center. Unlike the existing transportation system using road-based cargo trucks, the urban logistics system uses the existing urban railway to transport cargo to the destination area and then performs terminal delivery at the urban cargo destination. Figure 4 shows the operation scenario for the operation of the urban logistics system using the underground space. The steps for cargo warehousing and freight transportation are distinct from the operation of the urban logistics system using actual underground space, and the operational steps are carried out by cargo loading, cargo waiting, cargo unloading, cargo moving, cargo waiting, and cargo stacking.

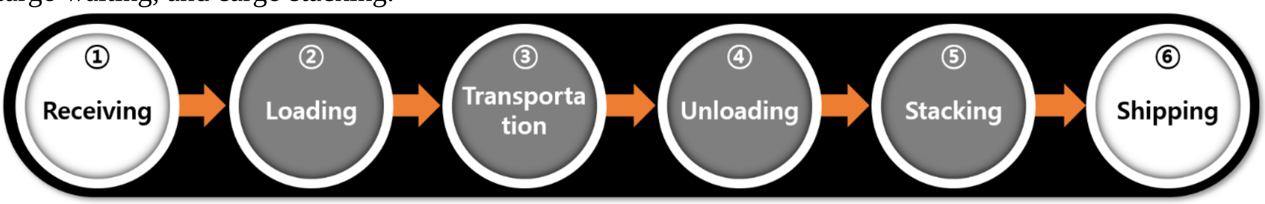

Figure 4. Logistics Space in Joint Logistics Terminal

Table 1 shows the operational step, facilities, and devices to achieve the purpose of the step-by-step system according to the operational scenario.

Table 1. Operation Scenario of Urban Logistics System Using Underground Space

Operational Step	Facilities	Device	Performance Role
cargo loading	Joint Logistics Terminal	standard container	When cargo is received, it is classified by delivery area and loaded into standard containers for cargo transportation.
		horizontal transfer	Move the horizontal transfer device to the place where the standard container for cargo transportation with cargo is located and interlock and combine with the standard container
cargo waiting	Cargo loading space in the platform	standard container & horizontal transfer	Waiting after the horizontal transfer device combined with the cargo transport container moves to the waiting space for cargo transport
cargo forwarding	cargo-only urban railway	cargo-only urban railway, standard container & horizontal transfer	When a freight-only urban railway arrives, move inside the train after the safety crossing board is opened.
			Start transportation after tying the cargo transport standard container inside the cargo-only urban railway train
cargo unloading	Cargo unloading space in the platform	standard container & horizontal transfer	When the cargo arrives at the destination station, the safety crossing board is opened after releasing the restraints in the cargo-only urban railway, and the standard container for cargo transportation and the horizontal transport device combined with it are disembarked.
cargo horizontal movement			Perform horizontal movement of cargo to move cargo to the vertical transport device within the platform.
cargo vertical movement	vertical transfer device	vertical transfer, standard container & horizontal transfer	Using a vertical transport device, the standard transport container loaded with cargo and the horizontal transport device combined with it are vertically moved between floors.

cargo waiting	Logistics space in the station	standard container & horizontal transfer	Waiting for the transported cargo in the logistics space within the station to prepare for terminal delivery and preparation for cargo loading when the terminal delivery vehicle enters the logistics space in the station.
cargo stacking		standard container	The horizontal transport device and the standard container for cargo transport are combined, and the cargo is loaded from the standard container for cargo transport to the terminal delivery vehicle and the dedicated transport container.

3. Analysis and Result

3.1 Analysis of Location Selection Factors

In this chapter, in order to derive the evaluation criteria for selecting a test-bed for an urban logistics system utilizing underground space, the location selection factors of existing logistics facilities are reviewed, and items that serve as evaluation criteria are analyzed. Through a literature review, factors for location selection of living logistics facilities were reviewed and items serving as evaluation criteria were analyzed. For the location selection of shared warehouses, Delphi surveys were conducted to derive criteria such as accessibility, scalability, security, facility and equipment cost, road type and condition, parking availability, population characteristics, and facility size [17].

In the "A Study on the Establishment and Application of Location Model for Location Selection of Public Service Facilities" conducted by the Chungnam Development Institute, a comparative analysis was conducted on location selection factors divided into natural environment, social economy, and legislation [18]. In the " Facility Locations and Scales of Logistics in Kyonggi-Do" conducted by the Kyonggi Development Institute, the surrounding logistics facilities, the status of cargo distribution, estimated cargo volume, product type, and transportation cost were suggested as factors for selecting the appropriate location of logistics facilities [19]. The Korea Research Institute for Human Settlements' "Evaluation Plan for Location Selection of Advanced Medical Complex" presented the location selection criteria for easy site security, financial and tax support, balanced national development, excellent R&D personnel, excellent R&D institutions, and excellent medical R&D institutions [20]. Factors for selecting the appropriate location of urban public facilities were classified into economic factors, social factors, transportation geographical factors, and natural environmental factors [21].

Based on the analysis of factors through literature research, evaluation factors for selecting a test bed for transporting cargo using an underground space were collected and evaluation items for location selection were selected through analysis. As evaluation factors for test-bed selection, the accessibility and scalability of test bed candidates, the cost of building station facilities and test-beds, transportation costs to logistics bases, and the size of idle space in the station were selected as location selection items. Table 2 shows the location selection factors obtained through literature research and the factors for selecting a test bed for an urban logistics system using an underground space.

Table 2. Analysis of Location Selection Factors Based on Literature

Analysis of Location Selection Factors Based on Literature	Location evaluation factors										
	Accessibility	Scalability	Facilities Environment	Facility cost	transportation cost	Distribution status	Peripheral facilities	Road Type	Facility size	Product Type	legal system

[17] P. S. Lee et al. (2021)	√	√		√			√	√	√		
[18] J. M. Yun, S. H. Lee (2008)			√					√			√
[19] S. H. Lee, K. D. Shin (1997)					√	√	√			√	
[20] C. K. Kim et al. (2016)			√				√		√		√
[21] H. Y. Park et al. (2010)	√		√	√			√	√			
This work	√	√	√	√	√				√		

3.2 Considerations for Selecting Test-beds through Operational Scenario Analysis

An urban distribution system utilizing an underground space is provided to transport to a destination station by using a freight-only urban railway and to show a series of processes to help terminal delivery to be performed in the destination station. In order to show these processes in detail, the operation scenario was derived in Section 2.3, and considerations were established when selecting the test bed station through analysis of the operation scenario.

Because the loading process is the beginning stage of cargo transportation, the loading and handling of cargo in the station is done. Therefore, in this process, it is important to consider whether there is sufficient space for moving and developing technologies to secure space for warehousing and processing. In the transportation process, freight trains are transported from the loading station to the destination station using freight trains. Freight trains should be able to be dispatched to the station, and waiting time is required for freight loading. In addition, there is a need for a free space in which the standard container for cargo transportation can be placed on the station platform. The disembarkation process is a process performed at the destination station and consists of a process of moving to the logistics space for terminal delivery. A space for moving the standard container of freight from the freight train to the vertical transfer device and an idle space for installing the vertical transfer device in the station must be considered. Finally, the loading process is a stage in which the standard container for cargo transportation, which has been brought up to the logistics space through the vertical transfer device at the destination station, is temporarily loaded for terminal delivery. The cargo transportation space and the loading space should be considered, and the cargo workspace for terminal delivery should be considered separately. Table 3 shows a summary of the considerations under the urban logistics freight transport process.

Table 3. Considerations for selecting testbeds through operational scenario analysis

Classification	Location	Process specific considerations
loading	departure station	• Cargo loading and parking space secured • Storage of standard cargo container and securing workspace • Whether the horizontal transport device has a moving space
transportation	freight train	• Whether the availability of a freight train • Whether it is possible to wait for a freight standard container to travel to a freight train. • Whether to secure air space in the station of the standard cargo container
unloading	arrival station	• Whether to secure air space in the station of the standard cargo container

		• Whether the horizontal transport device has a moving space • Whether the vertical transport device can be installed is secured
stacking	logistics space within the station	• Storage of standard cargo container and securing workspace • Whether to secure workspace for end-delivery operations • Whether the storage preparation space for standard cargo transport containers and horizontal transport devices for recovery transportation is secured

3.3 Evaluation Criteria of Test-bed Based on Urban Logistics System

When using the existing urban railway station as a logistics facility to build an urban logistics system using underground space, evaluation criteria for selecting a test bed were established. Based on the analysis of the location selection factors of the existing logistics facilities investigated earlier, the factors that can be used in selecting test bed candidates were identified and then refined to suit the environment of the urban railway system using underground space. Transportation accessibility factors and spatial factors should be considered to select a test bed for an urban logistics system using urban railway history in the city center. For the rapid transport of cargo, the conditions under which the means of transportation can move quickly and smoothly must be based, and securing space for storing, transshipment, or movement of cargo must be considered essential for logistics facilities. Therefore, in this study, detailed indicators were derived into a total of five major categories, including accessibility, location environment, and space security. As securing a logistics space in history was derived as the most important factor in the evaluation criteria, evaluation criteria and detailed factors that can emphasize this part were selected. Realistic evaluation criteria were derived through re-examination of idle spaces in existing stations. Table 4 shows the evaluation criteria and detailed factors finally derived for selecting a test bed for the application of an urban logistics system using an underground space.

Table 4. Selection of test-bed construction evaluation criteria candidate group

Category		Description
Infrastructure	Facility type	• The number of floors in the idle space • Station form
	Area	• The area of land divided by the inside and outside of a station
	Facility Utilization	• Availability and degree of utilization of urban railway related facilities
	Site Scalability	• Expandable Scale of Urban Railway Cargo History (Whether or not there is free space in the surrounding area and building)
Facilities/ Equipment	Technology Applicability	• Regions and locations that meet the requirements of R&D results and add elements for system operation
	Types and conditions of urban railway stations (interval of allocation, etc.)	• Types and Status of Existing History (Candidate Station) (Surrounding commercial area, dispatch interval, congestion degree, etc.)
	Whether to secure its own safety response facilities	• Whether to secure safety facilities to cope with emergencies
Accessibility	Regional accessibility	• The sum of the streets from each autonomous district in Seoul to the idle space
	Logistics Base Accessibility	• The sum of the distances from the designated railway logistics base to the idle space

	Accessibility of nearby safety response facilities	• Accessibility to nearby hazard response facilities to respond to emergency situations
Economical efficiency	Economic feasibility compared to existing road transportation	• Economic efficiency compared to the transportation of existing cargo vehicles
	Transportation costs	• Freight transportation costs (central place, logistics base, etc.)

4. Conclusion

The development of today's IT industry has led to the growth of the online logistics market, and the recent increase in non-face-to-face delivery due to the COVID-19 pandemic has accelerated the growth of the logistics market. As a result, the volume of parcels increased rapidly, and logistics and transportation in the city center increased. However, the increase in logistics and transportation in the city center has caused an increase in social costs, such as air environmental pollution caused by emissions from delivery trucks and increased traffic congestion caused by increased traffic. To solve this problem, many countries are seeking various methods to increase the efficiency of developing and delivering eco-friendly transportation systems. In addition, the development of a logistics delivery system using existing urban railway facilities and underground space infrastructure existing in the city is underway, and it is necessary to derive suitable test bed candidate stations to introduce them. In this study, evaluation criteria for selecting test bed candidates for the introduction of an underground logistics delivery system were established and presented. It is expected that it can be used to evaluate and select candidate roles based on the proposed evaluation criteria when selecting a test bed in the future.

Based on the evaluation criteria obtained first for the test bed selection and detailed factor design, the evaluation criteria were reviewed through logistics expert advice, and the final evaluation criteria were derived by collecting expert opinions.

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