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# Critical Success Factors of Underground Logistics Systems from the Project Life Cycle Perspective

**Dan Xue [1], Xiaojing Zhao [2,*], Jianjun Dong [3], Rui Ren [1], Yuanxian Xu [1] and Zhilong Chen [1]**

[1] School of Defense Engineering, Army Engineering University of PLA, Nanjing 210007, China
[2] School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China
[3] College of Civil Engineering, Nanjing Tech University, Nanjing 211816, China
* Correspondence: xiaojzhao@bit.edu.cn; Tel.: +86-10-8138-1076

**Abstract:** The surging demand for logistics systems brought about by the vigorous development of e-commerce makes urban traffic more and more congested. The need for a sustainable transition in terms of urban transportation infrastructure also encourages the further innovation of logistics systems. The urban underground logistics system (ULS) emerges as a promising alternative for realizing efficient large-scale freight distribution in megacities. However, there are relatively few studies that have explored the factors that determine the uptake of ULSs in practice. This paper thus aims to identify the critical success factors of ULSs throughout project life cycle stages. Firstly, a desktop study and a study using the Delphi method were conducted to extract the critical success factors (CSFs) of ULS projects. Secondly, a questionnaire survey was conducted to collect data on the perceived significance of the selected success factors from ULS professionals. Thirdly, the intergroup comparison of the significance of CSFs and exploratory factory analysis were used to ascertain the critical factors and latent determinants influencing the development of ULS projects. In total, 36 CSFs in the four life cycle stages of ULS projects were finalized. The identified factors represent the seven latent determinants in developing a ULS project, namely, overall feasibility and acceptance of the ULS, prototype system, and business model, competence and resources for ULS construction and operation, station layout and intermodal transportation, government policies and incentives, long-term planning of the underground space and logistics network, and market investigation and forecasting. The research findings of the paper help guide practitioners and policy makers on decisions made during ULS planning and construction and provide a reference performance evaluation framework for ULS projects.

**Keywords:** underground logistics system; critical success factor; project development; life cycle; sustainable transport

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## 1. Introduction

The logistics industry has developed rapidly with the development of urban traffic and the Internet, but it has also boosted pressure on the transportation system. The rapid development of urban logistics has also caused traffic congestion, environmental deterioration, and other problems. Urban freight transport takes up less than 10% of total urban traffic volume but accounts for 36% of carbon emissions and air pollutants associated with road traffic [1]. Further, urban freight transport contributes to between 25 and 40% of transport-related carbon footprints and GHG emissions. In addition, the conflict between surging demand and inadequate freight supply capacity requires the expansion of freight transportation networks [2]. According to the projections of the Organization for Economic Co-operation and Development (OECD), the global passenger-kilometers and freight transport demand will more than double by 2050, even if their growth rates diminish as a result of the global COVID-19 pandemic [3]. Since the 1980s, some scholars have proposed transferring the logistics system from on ground to underground, namely,

the underground logistics system (ULS). The ULS is physically defined as a set of underground depots and interconnected tunnels or pipelines that support 24 h all-weather goods movement and automated logistics operations [4]. As an alternative to the existing freight transport modes, ULSs can alleviate environmental pollution with electrical propulsion and realize the economic advantages of unimpeded automated transport and separation from passenger traffic.

Theoretical and empirical studies from various stages of ULS projects have been carried out in different countries to solve the problems of urban logistics distribution, garbage transportation, and other issues. Qian proposed a conceptual framework of ULSs at the city level [4]. Chen et al. applied freight locomotives in ULSs and studied the management and difficulties of freight locomotives from three aspects, namely conceptual design, network planning, and operation organization and management [5]. Wang and Wang established a dynamic sequential evolution map to analyze the construction route of ULSs from life cycle stages [6]. Chen et al. designed the main network and transportation route of a ULS based on demand prediction using a data-driven approach from three stages, i.e., design conceptualization, design scheme, and feasibility analysis [7]. In the Netherlands, a pilot underground freight transport project, 'Ondergronds Logistiek Systeem' (OLS-ASH) for Schiphol Airport, was executed in 1995 [8]. The ASCE Task Committee on Freight Pipelines of the Pipeline Division [9] discussed the obstacles hindering the development and use of pneumatic capsule pipelines for interstate transport of freight. O'Connell et al. explored capsule separation in pneumatic capsule pipeline underground freight transportation systems [10]. Although a number of countries have conducted trial projects on ULSs, a relatively fragmented amount of information and successful experiences can be retrieved from which to learn from. Considering the inherent complexity and novelty of ULSs, many obstacles exist in the development of ULS projects, including relatively higher upfront cost, a longer construction period, etc. Thus, despite the development of ULSs and industry practices, the ULS is still perceived as an emerging area. Existing studies mostly examined the ULS from two aspects: the technical operation mode of underground logistics and the network planning of the logistics system. Most of the ULS studies focused on the inception and planning stage considering the relatively few ongoing ULSs in practice in different countries. However, few scholars have studied the key determinants of the development of ULS projects.

Therefore, this paper examined the critical success factors (CSFs) of ULS projects from the project life cycle perspective. A questionnaire survey and statistical analysis were applied to identify the CSFs of ULSs. In total, 50 respondents' perspectives on the importance of CSFs were collected by the questionnaires. Identifying the CSFs throughout the life cycle of ULS projects and their significance helps crystalize bottlenecks in the development of ULSs, prioritize the scopes and tasks of ULSs, allocate resources rationally, and facilitate communication between different project stakeholders. The findings of the research help overcome the hindrance of a lack of development in terms of ULS projects in practice and provide references for academia to explore the in-depth network planning and design of ULSs.

## 2. Literature Review

In the 1970s, with the concept of "moving freight from above to underground", the ULS was formally proposed to address energy consumption, environmental pollution, and safety issues [11]. ULSs can quickly transport goods through underground pipes or tunnels within cities or between cities [12]. ULSs are a low-carbon and environment-friendly transportation that can help reduce urban pollution [13]. Moreover, ULSs could alleviate traffic congestion, increase city logistics efficiency, and improve the sustainability of urban areas [4].

A number of exemplar projects and engineering practices have been conducted to realize ULSs. One of the most popular applications is to build local ULS channels inside a logistics gateway to facilitate logistics operations. Dampier and Marinov proposed

the concept of "integrating underground freight transport into modern metro systems" (metro-based ULS, also known as M-ULS) [14]. In the M-ULS network, existing and new metro stations, trains, and tunnels are designed and retrofitted to integrate both passenger commute and logistics functions. In an ideal ULS network, interconnected tunnel and node facilities are established in the urban underground space to support automated transportation and logistics services for inner-city customers [15]. Another approach for realizing a ULS is based on pipelines. To reduce environmental impact, a pipeline was used in an Antwerp harbor project to transport containers [16]. A ULS project in Texas used a part of the underground space of existing right-of-way highways, especially interstate highways, which greatly facilitated the construction of pipelines and reduced the construction costs of the project [17]. Taking into account the limited capacity of the 'traditional' hinterland transport modes, a dedicated ULS was constructed to transfer containers between banks of the river Scheldt [18]. Heijden et al. developed a ULS using automatic guided vehicles around Schiphol Airport to avoid road congestion [19]. Scholars in the Netherlands used a ULS to ensure the in-time transport of goods such as flowers [17]. In Newcastle upon Tyne, light rail networks were used to deliver freight, including small-sized to medium-sized parcels, low-density high-value goods, and recyclable material [20].

Although there are some practical implementations of ULS projects, many difficulties still exist in the delivery process of ULS projects. The high cost, long construction period, and high risk of underground engineering are recognized as serious obstacles to the development of ULSs [21,22]. The current studies on ULSs mainly focus on three aspects: feasibility analysis, risk assessment, and network planning of the logistics system. Facility location (FLP) and vehicle routing (VRP) are two of the most critical influencing factors in logistics. Yang suggested that research and development of M-ULSs needs to address the following key influencing factors: a conceptual proposal, demand analysis, systematic planning, feasibility studies, prototype design, and an implementation scheme [23]. Optimal node location-allocation was deemed to be critical in the cooperative operation of M-ULSs [24]. According to the results of Dong et al. [24], an optimized M-ULS contributed to reducing the overall ground traffic volume by 49.09% and the daily comprehensive cost by 6.44%. Multimode facility location-routing is another factor that greatly affects the implementation efficiency and operation cost of ULSs [25]. Considering the uncertainty of logistics nodes, network planning is vital for managing the total cost and risk of ULSs [26]. Dynamic and uncertain graph programming have been applied to address the ULS planning issue [26]. Hu et al. [27] stated that M-ULS prototypes should fulfill the requirements associated with the demand flows, hierarchies, and facility features of an M-ULS network. Hu and Dong developed mathematical models and hybrid algorithms for the hub-and-spoke ULS network (ULH&S) design, achieving the minimization of facility construction cost and system operation costs [28,29]. Considering that no systematic reviews been conducted to examine the CSFs of ULSs, this study used a questionnaire survey and statistical analysis to identify the key influencing factors of ULS development.

## 3. Methodology and Data Presentation

A mixed approach consisting of a literature review, employment of the Delphi method, a questionnaire survey, and statistical analysis was adopted to achieve the research objectives, as presented in Figure 1.

First, a comprehensive literature review set the foundation of the study and was conducted to identify the preliminary CSFs of ULSs. Since ULS projects usually involve a broad variety of technical, personnel, and budgetary variables, the identification of CSFs should consider the dynamics of the project implementation process and the specialized features of success factors in each stage. Therefore, the life cycle theory was adopted as the theoretical basis of CSFs. A list of open-ended questions relating to the CSFs of ULSs was designed based on the desktop study. Expert consultation was then conducted with six government staff and industry experts through adoption of the Delphi method. The profile of the surveyed experts is shown in Table 1. Experts were invited to ascertain the CSFs of

ULSs and their significance and were asked to provide detailed explanations. All of the experts had at least five years of experience in ULSs or underground transportation. In order to provide a solid basis for the research, a modified Delphi method was used to assist the invited ULS experts in reaching an acceptable level of consensus on the CSFs [30]. The Delphi method was selected based on the results obtained from the literature review. Based on the literature review, a preliminary list of 38 CSFs based on the four stages of the life cycle were generated and used in the interviews with the selected experts. Each factor was accompanied by a 5-point Likert scale check box, where 5 indicated the greatest importance and 1 indicated the lowest importance. Participants were also invited to comment on the CSFs and add other factors based on their experience. Based on the first round of analysis, three additional CSFs were added, five were amended, and five were integrated with other factors. A summary of the results of the interviews was emailed to the respondents. The experts were invited to comment on the results and they provided a response on the following aspects: (a) the reasons they chose these CSFs as being important; (b) the real situation they faced during ULS implementation; and (c) how they implemented the CSFs correctly. In total, 36 factors throughout the four stages of ULS projects (i.e., inception, planning and design, construction, operation and maintenance) were finalized by identifying the consensus among expert opinions and eliminating irrelevant content.

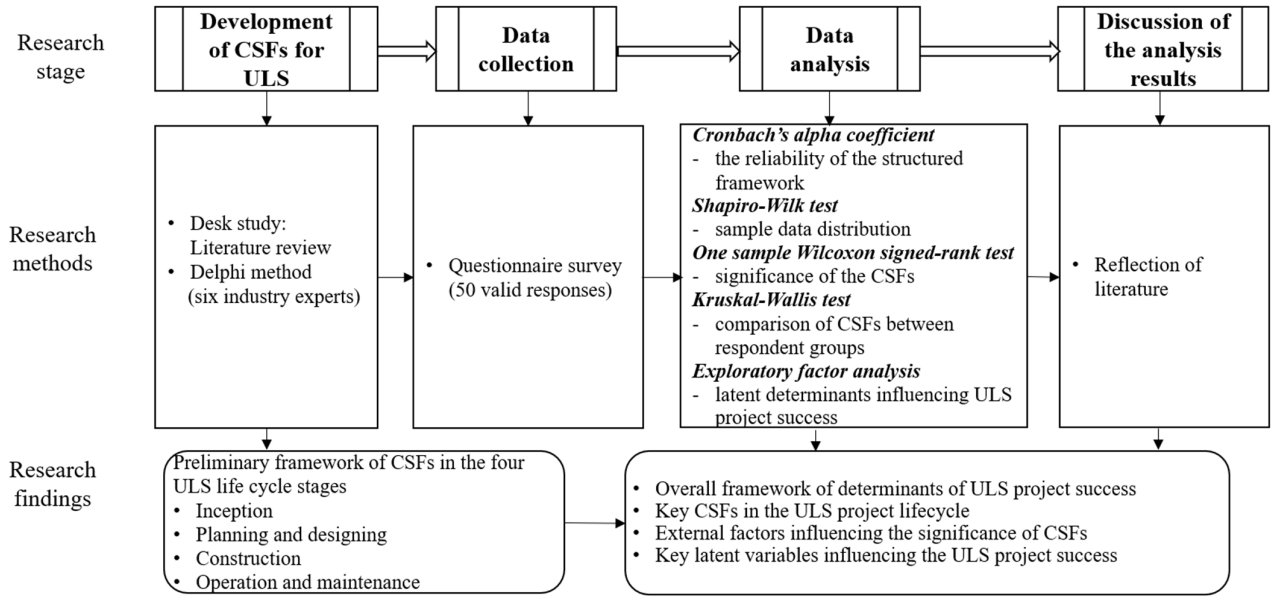



**Figure 1.** The methodology roadmap adopted in the study.

**Table 1.** Profile of consulted experts.

| Nature of Work | Designation | Age | Experience in Underground Transportation and Logistics Systems (yr) |
|---|---|---|---|
| Government | Director-general | 48 | 16 |
| Government | Director | 50 | 5 |
| University | Professor | 55 | 10 |
| Consultant | Project engineer | 45 | 10 |
| Contractor | Project manager | 39 | 8 |
| Consultant | Urban planner | 43 | 6 |

Based on the chosen factors, an empirical questionnaire survey was undertaken between February and May 2021 to analyze the CSFs that contribute to the success of ULS projects. Questionnaire surveys have been widely used to collect empirical data and ascertain the CSFs of infrastructure projects, such as in studies by Dampier and Marinov [14],

Zhao et al. [21], Hwang et al. [22], etc. In this study, the target survey respondents of the questionnaire included academia and industrial practitioners. Considering the relative infancy of ULS development in different countries, relatively few practitioners have been involved in the delivery of ULS projects. Thus, the target respondents were selected based on their direct hands-on involvement with ULS projects or their years of research experience with ULS projects. In addition, considering only a few ULS projects have been successfully launched and implemented, the investigation of the CSFs of ULS projects was targeted at experts in countries that had made progress in ULS development. In addition, it is worth mentioning that, since the implication of the study is not region-specific, the survey was targeted at researchers and industry practitioners who possessed experience with ULS projects.

Based on these factors, a questionnaire script was designed which consisted of two sections. First was a profile of respondents, and second was the level of significance for the CSFs from the respondents' perspective. For the first section, the basic information of respondents was collected, including nature of work, years of experience in relation to ULSs, the number of ULS projects they had engaged in, and nationality. For the second section, the CSFs were identified considering the tasks and challenges of ULS development in each stage. A 5-point Likert scale was used to solicit the survey respondents' attitudes towards the significance of CSFs (5 = most important, 4 = important, 3 = medium, 2 = slightly important, and 1 = unimportant). The significance of the CSFs was evaluated by respondents according to the impact and criticality of each factor in the life cycle stages of ULSs. The main tasks in the life cycle stages of a project were considered in the survey script, including feasibility, planning and coordinating with surrounding facilities, construction, efficient operation of systems, the market share of the ULS, etc. To simplify the complexity of ULSs, the CSFs of ULSs with single-line conditions were considered in the study. In most existing studies, ULSs were conceptually designed and implemented as a single line. For instance, Stein et al. designed an 80 km underground container transport route in Germany [31]. Liu and Lenau examined the technical and economical viability of a single ULS line in New York. The whole life cycle of single-route ULS projects is divided into the following four major phases: inception, planning and design, construction, and operation and maintenance [32].

The questionnaire was targeted at scholars and industry practitioners that possessed experience in ULS projects. The sampling frame consisted of researchers whose research focused on underground transportation or ULSs, consultants, architects, quantity surveyors, and engineers in registered construction companies with special qualification to work on underground space construction. A random sampling strategy was supplemented by a snowball sampling strategy and applied to select the survey sample. A total of 400 questionnaires were distributed via email and online survey tools between February and May 2021. By May 2021, 54 questionnaire responses had been collected. After removing four incomplete and erroneous responses, fifty valid responses were collected, representing a response rate of 12.5%. Although the sample size was not large, statistical analysis could be still performed since the central limit theorem holds true when the sample size is no less than 30, which is in accordance with the generally accepted rule [33]. In addition, the response rate was adequate compared to past studies using questionnaires that focused on underground facilities and infrastructure project management, with response rate ranging between 10 and 30% for studies such as those conducted by Zhao et al. [21], Hwang et al. [22], and Hwang et al. [34].

The profiles of the respondents are provided in Table 2. The group of respondents includes members of academia, government officers, and industrial practitioners. Nearly 60% of the respondents had over four years of experience in building and construction projects, which ensured that respondents could provide objective and reliable opinions concerning ULSs and their CSFs and implies that the collected information is reliable. In terms of the respondents' nature of work, 30 of the respondents are members of academia with experience in underground infrastructure or facilities, while the remaining are industrial practitioners with practical experience in ULS projects. It is worth mentioning

that, currently, there are relatively few ULS projects ongoing or in operation considering that ULSs are still at the inception stage in most countries, thus relatively few industry practitioners have experience in ULS projects. Comparatively, the amount of emphasis placed upon ULSs by researchers varies by country. Thus, the responses from academics are relatively high.

In terms of the number of ULS projects engaged with, 32 people (64%) had engaged with less than 3 ULS projects and 18 people had engaged with more than 3 projects. Considering the development of ULSs is in a start-up stage and relatively few projects have been established, the respondents generally had relatively rich project experience. Around two-thirds of respondents are Chinese professionals, and the remaining respondents come from nations with relatively rich experience and fast development in underground transportation and ULSs (such as the Netherlands, the United States, and Germany), which ensures the study has international relevance.

**Table 2.** Profile of survey respondents.

| Characteristics | Value | Frequency | Percentage (%) |
|---|---|---|---|
| Respondent (total = 50) | | | |
| Nature of work | Universities and educational institutions | 30 | 60 |
| | Government | 10 | 20 |
| | Industry | 10 | 20 |
| Experience in building and construction projects | ≤3 years | 21 | 42 |
| | 4–6 years | 22 | 44 |
| | ≥7 years | 7 | 14 |
| Number of ULS projects involved in | ≤2 | 32 | 64 |
| | 3 | 11 | 22 |
| | ≥4 | 7 | 14 |
| Nationality | China | 33 | 66 |
| | Netherlands | 4 | 8 |
| | USA | 2 | 4 |
| | Germany | 2 | 4 |
| | Japan | 3 | 6 |
| | Switzerland | 1 | 2 |
| | Singapore | 3 | 6 |
| | Others | 2 | 4 |

Statistical analysis was conducted to analyze the data collected from the survey using IBM's SPSS statistics software. SPSS Statistics 27.0 is one of the leading pieces of statistical software that is used to solve business and research problems through the use of descriptive statistics, hypothesis testing, and predictive analytics. It is a powerful tool for manipulating and deciphering survey data and visually representing analysis results. First, the reliability of the structured framework of CSFs was tested by using Cronbach's alpha coefficient. Cronbach's alpha coefficient was calculated for each of the four life cycle stages. If the Cronbach's alpha coefficient for the overall structure and for each category is larger than 0.7, this suggests the reliability of the structured framework. In addition, a Shapiro–Wilk test was conducted to test whether the sample data came from a normally distributed population [35]. If the $p$ value obtained from the test is less than the chosen alpha level, it suggests that the sample comes from a population that is not normally distributed. A value of 0.05 at a confidence interval of 95% was selected for the study. Since non-parametric methods such as the Wilcoxon signed-rank test, the Mann–Whitney–Wilcoxon test, and the Kruskal–Wallis test make fewer assumptions regarding sample distribution, they are generally more flexible and robust to use [36].

Second, one sample t-test or one sample Wilcoxon signed-rank test was adopted to examine whether the identified CSFs of ULS projects were statistically significant. In the case of normally distributed sample data, one sample t-test is used to check whether each

CSF is significant. The hypothesized critical significance value of each factor is set as 3. Otherwise, a one sample Wilcoxon signed-rank test is adopted.

Third, since the collected data can be categorized based on the respondent's designation, work experience, and nationality, analysis of variance (ANOVA) or a Kruskal–Wallis test was adopted for inter-group comparison to check whether there were significant differences in the perceived significance of CSFs between groups. The Kruskal–Wallis test is a non-parametric equivalent of ANOVA for distribution-free sample data [37]. ANOVA is commonly used to test the potential differences in means between different independent groups if the tested data are normally distributed. Moreover, the Cronbach's alpha coefficient was used to interpret the reliability of factors and the validity of questionnaires [38].

Lastly, exploratory factor analysis (EFA) was applied to find out the latent variables influencing the success of ULS projects from the observed factors. EFA was executed on the correlation matrix between the observed CSFs. A correlation test was first conducted to check whether there was significant correlation between indicators. Bartlett's test of sphericity and the Kaiser–Meyer–Olkin (KMO) test of sampling adequacy were used beforehand to check the extent of correlation between the observed CSFs, which helps justify the application of EFA. If the Bartlett spherical value is shown to be significant with a $p$ value less than 0.05, then the correlation matrix is significantly different to an identity matrix. For KMO values ranging from 0 to 1, KMO values larger than 0.70 indicate that the sampling is suitable for EFA, while values less than 0.6 indicate that the sampling is unsuitable for EFA [39]. If the correlation matrix is factorable, the varimax rotation method and rotated factor matrix were adopted as the factor extraction method. The commonality for each observed factor represents the relation between the variable and all other variables, the value of which should be higher than 0.4. The total variance explained for factors should be greater than 60%.

## 4. Analysis Results of the Collected Data

### *4.1. Preliminary CSFs of ULS Projects*

In total, 36 CSFs were extracted from the four life cycle stages of ULS projects based on the desktop study and the use of the Delphi method. The description of factors and codes, and their references, are presented in Table 3. In the inception stage, factors included research on the urban logistics market (such as urban transportation capacity, distribution efficiency of logistics enterprises, urban logistics demand, etc.), policy incentives (such as reducing corporate loan interest, policy initiatives regarding green transportation and smart logistics, etc.), and support from local governments. Eleven CSFs were included in the planning and design stage, including the prototype system (such as vehicle, loading and unloading equipment, transmission system, etc.), development and testing, and the participation of stakeholders (such as governments, logistics service providers, manufacturers, individual users, etc.) in planning and design. Eight factors were identified in the construction stage, including having an interdisciplinary/capable project team and the rational allocation of resources (human, material, financial, etc.). Eight factors were also identified in the operation stage, including intelligent operation and the management platform.

### *4.2. Reliability and Validity Analysis*

Reliability refers to the degree of consistency in terms of obtaining the same result through repeated measurement of the same thing using the same index or measurement tool. The Cronbach's alpha coefficient is used to interpret the reliability of factors and the validity of questionnaires. As shown in Table 4, the Cronbach's alpha coefficient for all CSFs is 0.975. The Cronbach's alpha coefficients for the four categories are larger than 0.7, which is greater than the baseline value of 0.7 and suggests the reliability of the structured framework [38].

**Table 3.** Summary of the CSFs of ULS projects.

| Life Cycle Stage | Code | CSF | References |
|---|---|---|---|
| Inception | I1 | Investigation of the urban logistics market (such as urban transportation capacity, distribution efficiency of logistics enterprises, urban logistics demand, etc.) | [19,28] |
| | I2 | Policy stimulus and incentives (such as reducing enterprise loan interest, policy initiatives for green transportation and smart logistics, etc.) | [5,19] |
| | I3 | Strong support from local government | [4,5,9] |
| | I4 | Public acceptance of the ULS | [7] |
| | I5 | Reliable operators and business models | [7,28] |
| | I6 | Investment and financing strategy based on cost-benefit analysis | [24,25,28] |
| | I7 | The availability of urban underground space | [12,17] |
| | I8 | The compatibility of the functional positioning of the ULS and urban planning | [24,27] |
| | I9 | The long-term planning for the development of the ULS network | [7,28,29] |
| Planning and design | P1 | Development and testing of prototype systems (such as vehicles, handling equipment, transmission systems, etc.) | [23,27] |
| | P2 | Stakeholder involvement in ULS planning and design (such as governments, logistics service providers, manufacturers, individual users, etc.) | [14] |
| | P3 | Ascertaining the project contracting mode | [7,27] |
| | P4 | Unified design specifications | [8,23] |
| | P5 | Designer's ability in relation to the ULS project | [7,19] |
| | P6 | Type of freight carried, flow direction and volume forecast | [27,29] |
| | P7 | Reasonable ULS operation route and station layout | [14,15] |
| | P8 | Coordination with underground space facilities (such as subway, underground parking lot, underground commercial facilities, etc.) | [4] |
| | P9 | Intermodal transportation with ground transportation system | [7] |
| | P10 | Design of the construction drawing and working plan | [8,19] |
| | P11 | Intact project management system | [19,21,36] |
| Construction | C1 | Interdisciplinary/competent project team | [8,19,21] |
| | C2 | Reasonable allocation of resources (human resource, material, financial, etc.) | [14,21] |
| | C3 | Green construction initiative | [2,13,36] |
| | C4 | Flexibility of construction, organizational, and governance structure | [21,22,28] |
| | C5 | Management of site worker safety and project risk | [22,34,37] |
| | C6 | Public supervision | [15,28] |
| | C7 | Support from the surrounding community | [6,28,29] |
| | C8 | The supporting facilities of the ULS that are constructed by government | [15] |
| Operation and maintenance | O1 | Smart operation management platform | [4,24] |
| | O2 | Competent operation team | [14,24] |
| | O3 | Training of users | [26,27] |
| | O4 | Marketing and brand building | [7] |
| | O5 | Reasonable and complete emergency plan | [6,27] |
| | O6 | Cooperation between ULS operators and other logistics service providers | [7,24] |
| | O7 | Establishment of a ULS policy system | [21,36] |
| | O8 | Effective communication between stakeholders (e.g., government, logistics service providers, manufacturers, individual users) | [4,36] |

**Table 4.** Reliability analysis of CSFs.

| Overall Cronbach's Alpha | Category | Cronbach's Alpha | N of Items |
|---|---|---|---|
| 0.975 | Inception | 0.867 | 9 |
| | Planning and design | 0.932 | 11 |
| | Construction | 0.920 | 8 |
| | Operation and maintenance | 0.925 | 8 |

As shown in Table 5, the *p* values for all CSFs obtained from the Shapiro–Wilk test are below the alpha value of 0.05 at a confidence interval of 95%, indicating that the sample data have a non-normal distribution. Thus, the rest of the analyses were conducted using non-parametric methods, including a one sample Wilcoxon signed-rank test, the Spearman correlation test, and the Kruskal–Wallis test. The results of the one sample Wilcoxon signed-rank test show that the assessment of significance for all the CSFs was greater than the test value of 3, showing that these CSFs were perceived to be critical in the development of ULS projects. In terms of the correlation test, most of the Spearman's rank correlation coefficient values fell between 0.3 and 0.7, indicating a moderate correlation between observed factors.

Ranking the CSFs, the top five CSFs in the full life cycle are the availability of urban underground space (I7), market investigation of urban logistics (I1), compatibility between the functional positioning of the ULS and urban planning (I8), long-term planning of the development of the ULS network (I9), and strong support from local governments (I3). All of these factors are from the inception stage, which suggests that the development of ULSs is still in its infancy. The availability of underground space directly determines whether there is room for development and utilization of underground space, as well as whether the ULS project can be carried out smoothly. In addition, reasonable planning and strong support from the government are also key to the efficient and reasonable utilization of underground space, which is an important prerequisite for the development of ULS projects.

**Table 5.** Perceived importance analysis of CSFs.

| Stage of Project Life Cycle | Code | Mean | *p* Value for Shapiro–Wilk Test | *p* Value for Wilcoxon Signed-Rank | Rank 1 | Rank 2 |
|---|---|---|---|---|---|---|
| Inception | I1 | 4.12 | 0.000 [a] | 0.000 [b] | 2 | 2 |
| | I2 | 3.92 | 0.000 [a] | 0.000 [b] | 10 | 7 |
| | I3 | 4.08 | 0.000 [a] | 0.000 [b] | 5 | 5 |
| | I4 | 3.44 | 0.000 [a] | 0.000 [b] | 27 | 9 |
| | I5 | 4.02 | 0.000 [a] | 0.000 [b] | 7 | 6 |
| | I6 | 3.88 | 0.000 [a] | 0.000 [b] | 12 | 8 |
| | I7 | 4.18 | 0.000 [a] | 0.000 [b] | 1 | 1 |
| | I8 | 4.12 | 0.000 [a] | 0.000 [b] | 3 | 2 |
| | I9 | 4.10 | 0.000 [a] | 0.000 [b] | 4 | 4 |
| Planning and design | P1 | 3.72 | 0.000 [a] | 0.000 [b] | 22 | 7 |
| | P2 | 3.74 | 0.000 [a] | 0.000 [b] | 21 | 6 |
| | P3 | 3.00 | 0.000 [a] | 0.000 [b] | 36 | 11 |
| | P4 | 3.42 | 0.000 [a] | 0.000 [b] | 29 | 9 |
| | P5 | 3.34 | 0.000 [a] | 0.000 [b] | 30 | 10 |
| | P6 | 3.88 | 0.000 [a] | 0.000 [b] | 13 | 4 |
| | P7 | 4.06 | 0.000 [a] | 0.000 [b] | 6 | 1 |
| | P8 | 4.00 | 0.000 [a] | 0.000 [b] | 9 | 2 |
| | P9 | 3.92 | 0.000 [a] | 0.000 [b] | 11 | 3 |
| | P10 | 3.44 | 0.000 [a] | 0.000 [b] | 28 | 8 |
| | P11 | 3.76 | 0.000 [a] | 0.000 [b] | 19 | 5 |

**Table 5.** *Cont.*

| Stage of Project Life Cycle | Code | Mean | *p* Value for Shapiro–Wilk Test | *p* Value for Wilcoxon Signed-Rank | Rank 1 | Rank 2 |
|---|---|---|---|---|---|---|
| Construction | C1 | 3.78 | 0.000 [a] | 0.000 [b] | 18 | 2 |
| | C2 | 3.68 | 0.000 [a] | 0.000 [b] | 24 | 4 |
| | C3 | 3.24 | 0.000 [a] | 0.000 [b] | 32 | 7 |
| | C4 | 3.22 | 0.000 [a] | 0.000 [b] | 33 | 8 |
| | C5 | 3.84 | 0.000 [a] | 0.000 [b] | 15 | 1 |
| | C6 | 3.28 | 0.000 [a] | 0.000 [b] | 31 | 6 |
| | C7 | 3.50 | 0.000 [a] | 0.000 [b] | 26 | 5 |
| | C8 | 3.72 | 0.000 [a] | 0.000 [b] | 23 | 3 |
| Operation and maintenance | O1 | 3.84 | 0.000 [a] | 0.000 [b] | 16 | 3 |
| | O2 | 3.76 | 0.000 [a] | 0.000 [b] | 20 | 5 |
| | O3 | 3.16 | 0.000 [a] | 0.000 [b] | 35 | 8 |
| | O4 | 3.20 | 0.000 [a] | 0.000 [b] | 34 | 7 |
| | O5 | 4.02 | 0.000 [a] | 0.000 [b] | 8 | 1 |
| | O6 | 3.68 | 0.000 [a] | 0.000 [b] | 25 | 6 |
| | O7 | 3.84 | 0.000 [a] | 0.000 [b] | 17 | 3 |
| | O8 | 3.86 | 0.000 [a] | 0.000 [b] | 14 | 2 |

[a] The Shapiro–Wilk test was significant at the significance level of 0.05. [b] The one sample Wilcoxon signed-rank test was significant at the significance level of 0.05. Rank 1 refers to the rank over the entire life cycle and Rank 2 refers to the rank at each stage.

In addition to the inception stage, the planning and design stage and its associated CSFs are another highly ranked category for the determinants of ULS project success. Reasonable ULS operation path and station layout (P7) (ranked 6th) and coordination with underground space facilities (P8) (ranked 9th) are two of the top ten ranked factors. To ensure the efficient operation of the ULS, two key indicators of the ULS's network design should be considered in the planning and design stage, namely, the freight flow path and site layout configuration and rationality [28]. These indicators directly affect the operation time and cost of the logistics system. Moreover, the functional classification of different types of facilities is necessary to meet the needs of intermodal transport. Existing subways, underground parking areas, and underground commercial facilities are the main facilities that may cause contradictions with the operation path and station layout of the ULS. In order to pursue higher logistics benefits, systematic planning and design of coordination efforts in relation to underground facilities is required when considering capacity constraints and system efficiency.

For the construction stage, the top three ranked CSFs are safety management and risk control (C5), having an interdisciplinary/competent project team in the construction stage (C1), and having supporting facilities for the ULS constructed by the government (C8). The development of ULSs helps improve traffic efficiency and safety. However, safety and risk management are key issues in the construction of ULSs considering the complexity and difficulties of underground construction. Underground construction projects, particularly those in urban areas, undergo more significant problems than other infrastructure projects. Technologies adopted in underground projects are normally more challenging than other projects, which exposes ULSs to more hazards and a higher chance of failure. The overall consequence of eventual failure in ULSs is more profound than in other projects. Moreover, having an interdisciplinary/competent project team is a prerequisite for ULS project success, with a mean of 3.78. The relatively higher complexity of ULS projects indicates an increased differentiation of sub-systems and a higher extent of interdependency/connection between intermodal aspects. Competent project organization, in terms of expertise and the ability to process more information, is important for project delivery. The development of ULSs in urban areas should integrate fragmented urban logistics (including B2C logistics, joint distribution, reverse logistics, close-loop logistics, and the last mile delivery) into a uniform, planned, capacitated tunnel or pipeline network that is integrated with transportation

and infrastructure facilities [29]. These supporting facilities should be uniformly planned, initiated, operated, and managed by the government and urban authorities.

For the operation and maintenance stage, effective and efficient facility management and emergency response within the ULSs are emphasized. The top CSF in this stage, ranked 8th in the overall project life cycle, is having a "reasonable and complete emergency plan" (O5), with a mean of 4.02. Rank 2 represents the ranking of individual CSFs in each life cycle stage. As shown by the Rank 2 values, the second CSF in this category is "effective communication between stakeholders (such as government, logistics service providers, manufacturers, individual users)" (O8).

### *4.3. Inter-Group Comparison of the Significance of CSFs*

The results of the Kruskal–Wallis test in Table 6 show the inter-group comparison of CSFs between respondents with different natures of work, work experiences, experience with ULSs, and nationalities.

**Table 6.** Inter-group comparison of the perceived significance of CSFs.

| Stage of Full Life Cycle | CSFs | *p* Value of Inter-Group Comparison | | | |
|---|---|---|---|---|---|
| | | Nature of Work | Years of Work Experience in Construction | Number of ULS Projects Engaged In | Nationality |
| Inception | I1 | 0.510 | 0.858 | 0.458 | 0.154 |
| | I2 | 0.964 | 0.570 | 0.076 * | 0.261 |
| | I3 | 0.739 | 0.850 | 0.607 | 0.381 |
| | I4 | 0.854 | 0.287 | 0.740 | 0.095 * |
| | I5 | 0.921 | 0.711 | 0.839 | 0.441 |
| | I6 | 0.233 | 0.350 | 0.313 | 0.707 |
| | I7 | 0.715 | 0.306 | 0.229 | 0.334 |
| | I8 | 0.808 | 0.609 | 0.205 | 0.969 |
| | I9 | 0.507 | 0.694 | 0.816 | 0.663 |
| Planning and design | P1 | 0.970 | 0.312 | 0.245 | 0.626 |
| | P2 | 0.985 | 0.849 | 0.686 | 0.542 |
| | P3 | 0.747 | 0.295 | 0.106 | 0.597 |
| | P4 | 0.981 | 0.550 | 0.739 | 0.368 |
| | P5 | 0.736 | 0.062 * | 0.456 | 0.484 |
| | P6 | 0.415 | 0.307 | 0.026 ** | 0.264 |
| | P7 | 0.720 | 0.372 | 0.381 | 0.180 |
| | P8 | 0.459 | 0.061 * | 0.405 | 0.627 |
| | P9 | 0.430 | 0.058 * | 0.296 | 0.817 |
| | P10 | 0.598 | 0.058 * | 0.306 | 0.253 |
| | P11 | 0.705 | 0.312 | 0.669 | 0.598 |
| Construction | C1 | 0.258 | 0.877 | 0.120 | 0.322 |
| | C2 | 0.196 | 0.406 | 0.233 | 0.527 |
| | C3 | 0.194 | 0.612 | 0.097 * | 0.288 |
| | C4 | 0.664 | 0.112 | 0.113 | 0.266 |
| | C5 | 0.784 | 0.219 | 0.506 | 0.865 |
| | C6 | 0.676 | 0.014 ** | 0.280 | 0.895 |
| | C7 | 0.974 | 0.453 | 0.626 | 0.575 |
| | C8 | 0.688 | 0.335 | 0.903 | 0.964 |
| Operation and maintenance | O1 | 0.984 | 0.251 | 0.466 | 0.456 |
| | O2 | 0.956 | 0.266 | 0.547 | 0.014 ** |
| | O3 | 0.929 | 0.156 | 0.852 | 0.042 ** |
| | O4 | 0.624 | 0.408 | 0.260 | 0.377 |
| | O5 | 0.387 | 0.318 | 0.447 | 0.832 |
| | O6 | 0.373 | 0.792 | 0.992 | 0.593 |
| | O7 | 0.082 * | 0.580 | 0.546 | 0.487 |
| | O8 | 0.224 | 0.724 | 0.921 | 0.773 |

* The Kruskal–Wallis test was significant at the significance level of 0.1. ** The Kruskal–Wallis test was significant at the significance level of 0.05.

For the inter-group comparison between different natures of work, all the $p$ values obtained were above the alpha level of 0.05 at a confidence interval of 95%. It is thus shown that nature of work has no significant effect on the significance of CSFs. For the comparison of respondents with different work experience, nearly all of the $p$ values obtained were above the alpha level of 0.05 at a confidence interval of 95%. "Type of freight carried, flow direction and volume forecast" (P6) had a significant difference in importance for respondents with different years of experience. "Public supervision" (C6) in the construction stage was perceived differently among respondents with a different number of ULS projects participated in.

For the inter-group comparison between respondents from different countries, the obtained $p$ values showed that the differences in the respondents' perceptions mainly concentrated on the CSFs in the operation and maintenance stage. Since nowadays ULSs are still normally considered to be at the inception stage, only a few projects have been successfully operated and maintained. Thus, the significance of factors in the operation and maintenance stage was perceived significantly differently by experts in different countries. The obtained $p$ values for "competent operation team" (O2) and "training users" (O3) were below 0.05, which suggested that the two factors were perceived differently by respondents in different countries. For example, O2 received a mean significance value of 3.88 from Chinese professionals, while this value was only 2.5 when assessed by Dutch professionals. O3 obtained a mean of significance of 3.24 in the Chinese professional group, while its mean significance was 1.75 among Dutch professionals. For the Kruskal–Wallis test, some differences in independent sample size are allowed. According to Field [30], the required sample sizes should be larger than 4, which holds true for the two independent respondent groups.

### *4.4. Latent Determinants of the Development of ULS Projects Based on EFA*

Table 7 presents the results of the KMO measure of sample adequacy and Bartlett's test of sphericity. The obtained KMO measure of sampling adequacy is 0.77, which is above the acceptable limit of 0.5 and indicates a relatively high proportion of variance in the observed CSFs that is caused by underlying factors. The significance value of the Bartlett test of sphericity is 0.000, which is significantly lower than 0.05. The results indicate that the correlation matrix diverges significantly from the identity matrix. The observed CSFs have strong correlations between them and are appropriate for data reduction techniques, i.e., EFA in this study. Considering the non-normal distribution of the population, the results of the Spearman correction matrix also support the strong correlations between observed CSFs.

**Table 7.** The KMO measure and Bartlett test for observed indicators.

| **Kaiser–Meyer–Olkin (KMO) Measure** | | **0.773** |
|---|---|---|
| Bartlett test of sphericity | Approx. chi-square | 1759.283 |
| | Degrees of freedom | 630 |
| | Significance | 0.000 |

Since there is a strong correlation between the observed variables, principal component analysis (PCA) was applied as the factor extraction method to explore the latent determinants of CSFs for ULS projects. Varimax with the Kaiser normalization method and rotated factor matrix were selected as the rotation method.

As shown in Table 8, seven latent determinants had eigenvalues above one, which shows that seven factors can be extracted from the CSFs of ULS projects. The seven latent determinants in total accounted for a cumulative variance of 76.24%, which shows that these extracted components can explain most of the information represented by the 36 factors. The results of the rotation make the latent determinants of ULS projects reliable to name and explain. The first determinant, I, accounts for 50.94% of the total variance. After rotation, the latent determinant I is comprised of eight CSFs and explains 16.52% of the total

variance. Determinant II also contains eight CSFs and accounts for 16.17% of the variance. Determinant III contains eight CSFs and explains 14.23% of the variance. Determinant IV contains three CSFs and the last three determinants contain two items each, accounting for 8.20%, 7.90%, 6.87%, and 6.35% of the variance, respectively.

**Table 8.** Total variance explained for CSFs in the ULS projects.

| Code | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| I | 18.339 | 50.940 | 50.940 | 18.339 | 50.940 | 50.940 | 5.947 | 16.520 | 16.520 |
| II | 2.297 | 6.380 | 57.321 | 2.297 | 6.380 | 57.321 | 5.820 | 16.167 | 32.687 |
| III | 2.097 | 5.826 | 63.147 | 2.097 | 5.826 | 63.147 | 5.123 | 14.232 | 46.919 |
| IV | 1.354 | 3.762 | 66.909 | 1.354 | 3.762 | 66.909 | 2.954 | 8.204 | 55.123 |
| V | 1.205 | 3.348 | 70.257 | 1.205 | 3.348 | 70.257 | 2.844 | 7.899 | 63.022 |
| VI | 1.114 | 3.094 | 73.352 | 1.114 | 3.094 | 73.352 | 2.474 | 6.873 | 69.895 |
| VII | 1.041 | 2.891 | 76.243 | 1.041 | 2.891 | 76.243 | 2.285 | 6.347 | 76.243 |

Note: principal component analysis is used as the extraction method.

As presented in Table 9, the rotated component matrix indices for each CSF show the loading of each factor to the extracted component. Factor loading values for all CSFs are above 0.40; therefore, no observed factors need to be removed on the basis of this criterion [40]. The factor loading indices of 34 CSFs are above 0.5 (aside from O3 and O5), which indicates a strong correlation for each observed factor with the latent determinants. The communality of each factor is the sum of the squared component loadings up to the seven latent determinants extracted. The communalities of the 36 factors are above 0.65, which indicates that the factor model accounted for the majority of variance in the CSFs [41].

**Table 9.** Rotated component matrix and communalities of the CSFs in ULS projects.

| Code | Component | | | | | | | Communalities |
|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | |
| I4 | 0.582 | 0.225 | 0.184 | −0.090 | 0.452 | 0.153 | 0.212 | 0.704 |
| P3 | 0.696 | 0.414 | 0.176 | 0.034 | 0.031 | 0.185 | 0.227 | 0.775 |
| P5 | 0.579 | 0.498 | 0.065 | 0.219 | 0.122 | 0.246 | 0.150 | 0.734 |
| P10 | 0.711 | 0.374 | 0.255 | 0.220 | 0.073 | 0.107 | 0.017 | 0.776 |
| C3 | 0.817 | 0.113 | 0.202 | 0.138 | 0.037 | 0.337 | −0.046 | 0.858 |
| C4 | 0.713 | 0.308 | 0.453 | 0.144 | 0.096 | 0.071 | −0.082 | 0.850 |
| C6 | 0.690 | 0.278 | 0.222 | 0.277 | 0.277 | 0.010 | 0.071 | 0.761 |
| C7 | 0.518 | 0.145 | 0.328 | 0.406 | 0.434 | −0.068 | 0.006 | 0.754 |
| O3 | 0.494 | 0.235 | 0.492 | 0.046 | 0.333 | 0.139 | 0.144 | 0.694 |
| I5 | 0.202 | 0.636 | 0.254 | 0.062 | 0.097 | 0.290 | 0.218 | 0.655 |
| P1 | 0.227 | 0.683 | 0.357 | 0.099 | −0.103 | 0.117 | 0.181 | 0.712 |
| P2 | 0.468 | 0.517 | 0.174 | 0.373 | 0.174 | 0.095 | 0.047 | 0.696 |
| P4 | 0.375 | 0.512 | 0.032 | 0.367 | 0.332 | 0.269 | −0.067 | 0.726 |
| P11 | 0.361 | 0.660 | 0.297 | 0.279 | −0.027 | 0.174 | 0.054 | 0.766 |
| C5 | 0.421 | 0.588 | 0.097 | 0.228 | 0.191 | −0.105 | 0.229 | 0.684 |
| C8 | 0.302 | 0.667 | 0.166 | 0.320 | 0.248 | 0.049 | 0.097 | 0.739 |
| O1 | 0.169 | 0.709 | 0.187 | 0.028 | 0.289 | 0.211 | 0.072 | 0.700 |
| C1 | 0.465 | 0.146 | 0.671 | 0.235 | 0.086 | 0.137 | −0.012 | 0.769 |
| C2 | 0.461 | 0.118 | 0.556 | 0.394 | −0.027 | 0.255 | 0.086 | 0.764 |
| O2 | 0.259 | 0.488 | 0.683 | −0.090 | 0.074 | 0.100 | 0.172 | 0.825 |
| O4 | 0.363 | 0.115 | 0.593 | 0.138 | 0.312 | 0.159 | 0.293 | 0.725 |
| O5 | 0.187 | 0.452 | 0.484 | 0.383 | 0.034 | 0.297 | 0.141 | 0.730 |
| O6 | 0.126 | 0.254 | 0.626 | 0.204 | 0.392 | 0.310 | 0.092 | 0.772 |
| O7 | 0.102 | 0.193 | 0.803 | 0.162 | 0.340 | 0.005 | 0.087 | 0.842 |
| O8 | 0.285 | 0.403 | 0.613 | 0.195 | 0.269 | 0.236 | 0.022 | 0.785 |
| P7 | 0.100 | 0.425 | 0.150 | 0.578 | −0.022 | 0.187 | 0.484 | 0.817 |
| P8 | 0.296 | 0.190 | 0.299 | 0.709 | 0.114 | 0.137 | 0.201 | 0.789 |

**Table 9.** *Cont.*

| Code | Component | | | | | | | Communalities |
|---|---|---|---|---|---|---|---|---|
| | I | II | III | IV | V | VI | VII | |
| P9 | 0.223 | 0.432 | 0.211 | 0.529 | 0.237 | 0.234 | 0.154 | 0.696 |
| I2 | 0.234 | −0.039 | 0.354 | −0.019 | 0.780 | 0.102 | 0.125 | 0.816 |
| I3 | 0.044 | 0.376 | 0.216 | 0.247 | 0.750 | 0.138 | 0.058 | 0.836 |
| I7 | 0.191 | 0.330 | 0.043 | 0.291 | 0.266 | 0.632 | 0.347 | 0.822 |
| I9 | 0.242 | 0.269 | 0.268 | 0.060 | 0.046 | 0.780 | −0.029 | 0.817 |
| I1 | −0.079 | 0.089 | 0.169 | 0.059 | 0.160 | 0.085 | 0.854 | 0.809 |
| P6 | 0.271 | 0.431 | 0.012 | 0.300 | −0.027 | 0.053 | 0.668 | 0.800 |

The first principal determinant of ULSs contains information about I4, P3, P5, P10, C3, C4, C6, C7, and O3. Loading of the nine CSFs to determinant I ranged from 0.494 to 0.817. Among these, "green construction initiative" (C3) had a correlation value of 0.817 with determinant I. "Flexibility of construction, organizational, and governance structure" (C4) had a correlation value of 0.713 with determinant I. The information in the first principal determinant contains the feasibility and acceptance of ULSs from inception to the end users, and can therefore be labelled as "overall feasibility and acceptance of ULS system development".

The second principal determinant contains information about I5, P1, P2, P4, P11, C5, C8, and O1. The first and second latent determinants accounted for 57.321% of the total variance, with an eigenvalue of 2.297. Loading of the nine CSFs to determinant I ranged from 0.512 to 0.709. Among these, "intelligent operation management platform" (O1) had a correlation value of 0.709 with determinant II. "Development and testing of prototype systems (such as vehicles, handling equipment, transmission systems, etc.)" (P1) had a correlation value of 0.683 with determinant II. The majority of the information expressed in the determinant expresses the prototype system and business model used to deliver the ULS project, including the planning and contracting mode. Thus, determinant II can be labelled as "prototype system and business model".

The third principal component contains information of eight CSFs, i.e., C1, C2, O2, O4, O5, O6, O7, and O8. The top three components accounted for 63.147% of the total variance, with an eigenvalue of 2.097. Loading of the nine CSFs to determinant I ranged from 0.484 to 0.803. "Establishment of a ULS policy system" (O7) had a correlation value of 0.803 with determinant III. "Competent operation team" (O2) had a correlation value of 0.683 with determinant III. Determinant III focuses on the competence and policy environment to ensure the construction and operation management of the USL project, and can thus be labelled as "competence and resources for ULS construction and operation".

The fourth principal determinant contains information about P7, P8, and P9, and all of the items are closely related to the hub-and-spoke-level ULS design and its intermodal coordination with ground/underground transportation systems; therefore, it is labelled as "ULS station layout and intermodal transportation". The fifth principal determinant, V, contains information about "policy incentives" (I2) and "strong support from local government" (O3), with loadings of 0.780 and 0.750, respectively. Thus, it can be named "government policies and incentives".

Similarly, determinant VI was labelled as "long-term planning of the underground space and logistic network" considering the two CSFs (I7 and I9) included in the sixth principal component. The seventh determinant, VII, mainly considers "market investigation and forecast of ULS systems". Economic viability is one of the vital success factors prior to the development of a project. "Market investigation of urban logistics (such as urban transportation capacity, distribution efficiency of logistics enterprises, urban logistics demand, etc.)" (I1) and "type of goods carried, flow direction, and flow forecast" (P6) should be investigated in the inception and planning stage.

## 5. Discussion

This paper ascertained the 36 critical factors influencing the success of ULS projects, which can be grouped from two perspectives: project life cycle stages and systematic latent determinants.

### *5.1. CSFs from the Life Cycle Perspective*

According to the mean rank shown in Table 5, the inception stage and its related CSFs were emphasized by survey respondents. In the top-ranked CSFs, seven factors focused on the inception stage. The results indicate that the application of underground logistics is still in the start-up stage and that the concept of ULSs is novel for industry practitioners. Currently, ULSs have been put on the agenda of worldwide regions, and ULSs are commonly considered to be an advanced intelligent transportation system that greatly improves the efficiency and sustainability of urban logistics systems. Different types of transportation technology and locomotion have been designed for ULSs, such as pneumatic capsule pipelines in the USA and CargoCap in Germany [27,42]. However, the large-scale development and diffusion of ULS infrastructure require systematic research and planning. In the inception stage, policies and stimulus from the local authorities are essential to large-scale urban infrastructure development [4]. As an innovative solution to challenges faced by urban logistics systems, many basic logistics elements for ULSs need to be clarified in the inception stage. Industry standards and guidance should be established to meet the needs of ULS engineering practice, which usually specifies urban long-term development, underground space and resources management, and refined management of underground facilities such as rail transit, pipe corridors, and underground parking lots. One of the key concerns of master planning for ULSs is the coordination of different surface function systems with underground logistics, as well as compilation in line with urban master planning. In addition, the uptake of ULSs requires a closer collaboration between different disciplines compared to other infrastructure projects, such as urban underground planning, implementation agencies, potential operators, and research institutions. The issues existing in previous ULS projects include unchecked and scattered development, unbalanced function, limited overall benefits, and low efficiency [36]. Enhancing collaboration helps to eliminate silo thinking, plan the space beneath the ground systematically, and promote the best solutions for urban logistics, transportation, landscape, groundwater, and geological conditions. Additionally, total coordination of multiple disciplines (e.g., urban planning, logistics, urban space, and comprehensive transportation) and advancements in the planning and implementation of ULSs can be achieved through different development stages, such as R&D, planning, construction, and operation management. Underground space planners need to reflect and deliberate on their role in this process. The results are consistent with the findings of Xu et al. [19], which stated that "dynamic policy support from government is necessary in the development of metro-based ULSs based on market changes in the development process, including franchise operation, mandatory resource allocation, and extensive guidance".

As an innovative transportation infrastructure, ULSs have close interaction with urban development. Transport network density and scale determine the capacity of a ULS. According to the feedback of surveyed experts, acquisition of the right to use underground space/resources, the standard of the transfer fee, property rights registration, and investment and financing mechanisms are the main content in the regulations relating to underground space development.

Considering there are relatively few projects for practical reference, research on the life cycle cost and benefit analysis of ULSs is still lacking; therefore, the market potential and forecast (I1) were emphasized. Estimation of the performance of ULSs is complex considering the inherent complexity of the system, the costly construction and operation of the underground project, and the surging demand of urban freight transportation volume. Scenario analysis and system dynamics analysis were applied by Xu et al. [19] to measure the city logistics performance of metro-based ULS operation. The findings support the

effectiveness of ULSs in shortening the delivery time of city logistics and responding to the epidemic, while delivery time and transportation cost are closed correlated with the market share of a ULS. Hu et al. [28] applied system dynamics and agent-based modeling to evaluate the long-term development of a city-wide ULS project in Beijing and found that the construction cost of the ULS can be largely compensated for by the external benefits of the ULS and the profit of the ULS when the system is performing well in the project operation stage.

Aside from the inception stage, the system design of ULSs in the planning and design stage has been found to be critical to the success of ULS projects. "Reasonable ULS operation path and station layout" (P7) and "coordination with underground space facilities" (P8) are also included in the top ten CSFs. Research on the planning of the ULS also explored the following elements: type of transport and locomotion [24,26,42,43]; network planning and design [24,25,27]; and hub layout configuration and rationality [27,43]. Among the different means of transportation, metro-based M-ULSs received great attention due to their compatibility with existing underground facilities and networks, which will generate less upfront cost, lower construction costs, and provide higher feasibility [43]. The economic viability of the integration between underground freight transportation and existing intermodal systems has also been examined by measures such as net present value (NPV), the benefit–cost ratio of each system, and the system's internal rate of return [17].

Compared to the CSFs in the inception and planning stage, CSFs in the construction stage received lower significance and ranking. The results suggest the relatively mature technological underpinning of ULSs. As mentioned in Dong et al. [24], various types of automated transport vehicles or vessels with various sizes and functions have been invented to meet the needs of logistics.

### *5.2. CSFs from the Latent Determinant Perspective*

In total, 36 CSFs of ULSs can be grouped in seven categories, namely, overall feasibility and acceptance of ULS development, the prototype system and business model, competence and resources for ULS construction and operation, ULS station layout and intermodal transportation, government policies and incentives, long-term planning of the underground space and logistics network, and market investigation and forecasting of the ULS. The first three principal determinants extracted contain 25 CSFs. The results echo with the analysis results from the project life cycle perspective and emphasized the significance of market acceptance and the project feasibility of the ULS. As a semi-public system, the successful development of a ULS needs both feasible engineering practices and a viable innovative business model. Considering that relatively few successful ULS projects exist, the comprehensive assessment of the political, economic, social, and environmental benefits/costs in relation to ULSs is still deficient. The factors that should be considered in the assessment include the volume of underground resources, natural reserves, potential reserves for further exploration, urban spatial allocation conditions, land use function, etc. In China, ULSs have recently been officially adopted as an innovative means for new city and district development, such as the planning and research conducted for Beijing's Sub-Center, the Yangtze River Demonstration District, and other new cities and districts [44]. It is worth mentioning that reform of the manpower-intensive urban transportation mode is urgent in the post-epidemic era. ULSs help develop contactless smart city logistics systems and are expected to reach a higher market acceptance rate [19].

The prototype system and business model of a ULS represent another aspect that researchers and industry practitioners are focused on. Citizens' preference towards public measures for dealing with freight externalities were examined with the aim of promoting decarbonization and sustainability in urban logistics literature, such as the findings reported in [45]. Additionally, urban transportation solutions designed to confront the challenges of space, access, and distance in urban areas were designed by using better transport network designs and last mile delivery and collection, as reported in a study by Wiese et al. [46]. The density and scale of network implementations of ULSs with high transport capacity

can obviously greatly improve the efficiency of urban logistics. In addition, the capacity of the ULS is inversely proportional to ground transport vehicles, which addresses traffic congestion and environment pollution.

The development of ULSs has great potential for improving the efficiency and sustainability of urban logistics. The literature on urban logistics sheds light on the business model design of a ULS project. At the macro system design level, policies, environment targets, available resources, and stakeholders involved in urban logistics should be considered in a systematic manner. At the meso level, the ULS network design, hub-and-spoke design, station layout, and the interaction between the ULS and other transportation facilities should be designed. At the micro level, the last mile logistics operation issues should be optimized considering economic, social, and environmental performance.

## 6. Conclusions

The development of ULSs is considered to be an innovative and environmental-friendly transportation system that can realize efficient automated freight distribution in megacities. Due to inherent complexity and the lack of practical applications of ULSs, unclear determinants of the development of ULS projects have become an important obstacle to large-scale implementation. The lack of quantitative analysis and practical verification might lead to the overestimation or underestimation of ULS functions or associated environmental/social benefits. Therefore, this paper explores the success factors influencing the development of ULS projects in a systems manner. The paper has identified and ranked the key factors influencing the success of ULSs through a comprehensive literature review, use of the Delphi method, and a questionnaire survey with 50 professionals covering major stakeholder groups. In total, 36 CSFs are identified, which cover four project life cycle stages and are grouped in seven latent determinant categories.

The CSFs in the project inception stage are found to be most critical to the development of ULSs. After ranking, the top five factors are the availability of urban underground space, market investigation of urban logistics, compatibility between the functional positioning of the ULS and urban planning, the long-term planning of the development of the ULS network, and strong support from local government, which suggests that the development of ULSs is still in its infancy. In addition, the reasonable planning of ULS operation paths and station layouts is key to the efficient and reasonable utilization of underground space, which is an important prerequisite for the development of ULS projects.

The results of the inter-group comparison show that no significant difference in perceived importance for most of the CSFs was found between respondents with different natures of work, work experiences, experiences with ULSs, or nationalities.

The results of EFA showed that 36 CSFs of ULSs can be categorized into seven key latent determinants, namely, overall feasibility and acceptance of ULS development, the prototype system and business model, competence and resources for ULS construction and operation, ULS station layout and intermodal transportation, government policies and incentives, long-term planning of the underground space and logistics network, and market investigation and forecasting of the ULS system. The seven components account for 76.243% of the total variance of the 36 CSFs.

The research findings of the paper highlight the criticality of the urban planning stage in the implementation of ULS projects. Due the relatively few examples of ULSs in industry, developers need to ascertain the functional positioning of the ULS system and the availability of underground space. It is also vital to examine the market potential and long-term planning of the system. In the development of ULS projects, the prototype system and business model of the ULS should be ascertained considering long-term service life and the difficulty in replacing parts in underground infrastructure projects.

The identified critical influencing factors should help developers, designers, and contractors to better understand the opportunities and challenges of ULS development and thus cultivate innovative business models for ULS delivery. The findings not only provide a systematic perspective for the planning and developing of ULS projects, but also

offer policy makers greater incentive to delve into more detailed and practical standards on underground space development and underground logistics planning. Since the ULS is highly dependent on policy incentives and regulatory frameworks, policy makers should rethink current policy instruments and legislations with the goal of fostering a favorable environment for underground space development. The findings of the paper will also help developers and other stakeholders better set their business strategies and convert the value of ULSs into economic, social, and environmental value.

Limitations of the study may be attributable to two elements: the relatively limited number of survey respondents and the limited scope of the survey's context. Nevertheless, the derived findings can be a valuable reference when examining the feasibility and development of ULSs in other regions. Future research should test the applicability of the CSFs with a larger sample size and test the model in different countries/regions. Future research should also examine how ULSs evolve and reconfigure over certain periods of time under the influence of the identified CSFs.

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