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Development Prospects and Literature Research on the Application of Underground Logistics Systems (ULS) in Logistics Field

Xinyue Zhang[1]

[1] Inha University, Incheon, South Korea
Correspondence: Xinyue Zhang, Inha University, Incheon, South Korea.

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Abstract

This paper explores the development prospects of Underground Logistics Systems (ULS) within the context of Green Logistics. It uses a comprehensive methodology, combining literature reviews and advanced visualization tools such as CiteSpace, VOSviewer, and Bibliometrix (R language). The primary goals are to deepen understanding, identify emerging trends, and provide decision-making support for ULS implementation.

The research methodology includes both quantitative analysis and case studies, with a specific focus on cost-benefit analysis. Key findings reveal a concentration of ULS research activities in China and Europe, along with a noticeable increase in research volume over time. Visualizations of key words, influential authors, and cited references offer valuable insights into the current state of ULS research.

Furthermore, the study aims for a qualitative assessment, decision support, and empirical validation of ULS, emphasizing its economic feasibility and impact on traffic management, logistics optimization, environmental sustainability, and societal benefits. In the final phase, the research conducts a cost comparison between the ongoing project from Shanghai Waigaoqiao Port to Jiading District and traditional land truck transportation. The paper concludes by summarizing the advantages and disadvantages of this specific project.

This research contributes valuable insights to the literature, providing a comprehensive overview of ULS. The detailed analysis and comparisons aim to inform decision-makers in the transportation and logistics sectors, offering a robust foundation for further exploration and implementation of UCLS.

Keywords: Underground Logistics Systems (ULS), Underground Container Logistics Systems (UCLS), Green Logistics, literature visualization, case study

1. Research Background

Traditional port container transport faces multifaceted challenges, notably encompassing issues such as traffic congestion, suboptimal land utilization, and environmental pollution. These challenges collectively impede the efficiency and hinder the sustainable development of container transport within ports (Lai, 2011). The rapid pace of urbanization and the growing shortage of land have made it even

more urgent to tackle these challenges, driving greater interest in using underground spaces as potential solutions.

Amid these challenges, the development of the UCLS offers a promising way to transform cargo transportation by making strategic use of underground spaces. Advances in technology, improved underground construction methods, and the integration of automated loading and unloading equipment make the UCLS a practical and viable area for further research and development (Peng, 2023).

Several countries and regions have actively explored the practical applications and research related to UCLS. Notable examples, such as the 'Cargo Sous Terrain' project in Switzerland, which is set to begin deliveries in 2031, not only highlight the potential of such systems but also provide valuable insights and learning opportunities for other regions aiming to undertake similar initiatives (Schodl, 2018).

This research provides valuable contributions to the existing literature by offering a comprehensive overview of ULS within the context of Green Logistics. The in-depth analyses and comparisons are purposefully structured to inform decision-makers in the transportation and logistics sectors, laying a solid foundation for further exploration and implementation of ULS.

The remainder of this paper is organized as follows. Section 2 contains a literature review. Section 3 contains the research methodology, the process of literature analysis and the related situation are introduced. Section 4 consists of the present research results. Section 5 presents a case study. Section 6 outlines the findings of this study and provides policy implications.

2. Literature Review

UCLS, which move a proportion of freight within the city underground through pipes or tunnels, can effectively reduce traffic congestion and improve freight efficiency while saving land, energy, and other resources, reducing environmental pollution and reducing traffic accidents (Fan & Qian, 2011). Hai (2020) explores the establishment of a collection and distribution model based on the UCLS to address the conflict between port operations and urban development, while promoting their integrated growth. Using Shanghai Port as a case study, he proposes and evaluates a layout plan that considers traffic, economic, and social benefits.

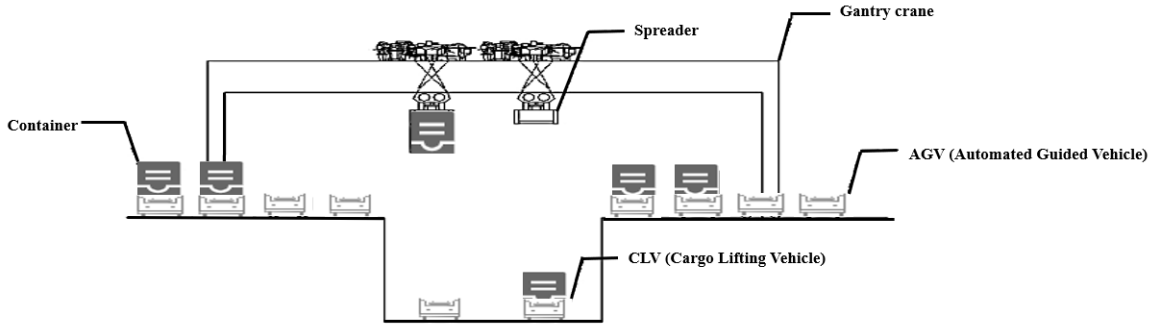

Figure 1. A cross-section of an underground container logistics system

As an innovative logistics and transport system, the underground container logistics system provides a new solution for port consolidation and distribution. Chen (2017) believes that this system can contribute to optimizing logistics and transport efficiency. Firstly, optimizing the design and layout of the underground passageways can better match the flow and needs of port cargo. In addition, advanced automated loading and unloading equipment and technology can improve the efficiency and accuracy of loading and unloading operations.

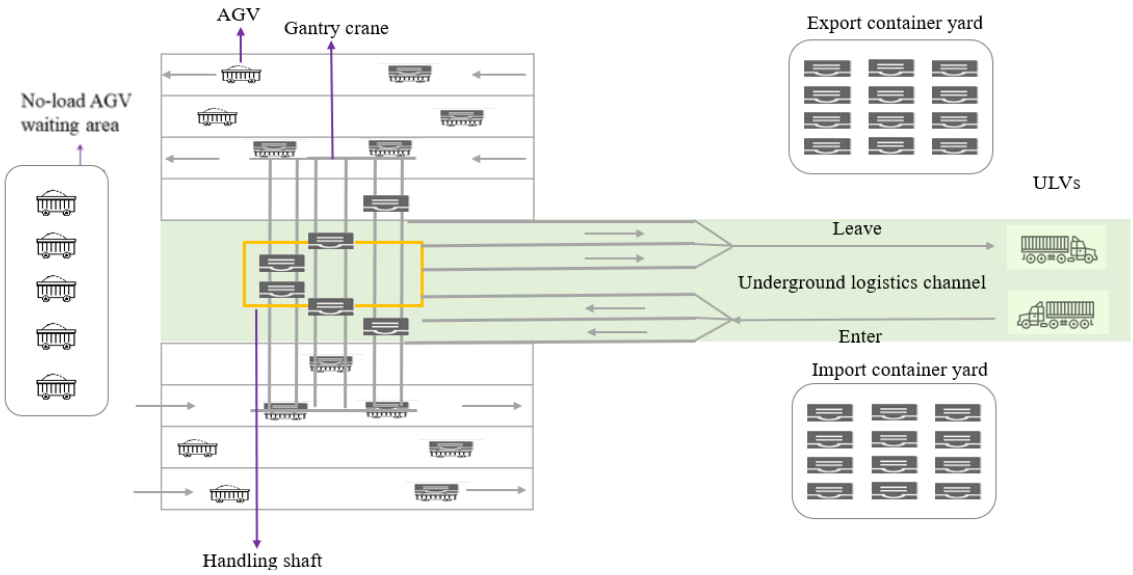

Figure 2. Schematic of the connection of the UCLS and automated container terminal area

Kesi (2019) argues that the UCLS can reduce transport costs by considering factors such as cargo flow, distance, and energy consumption. He develops a transport plan and cost structure aimed at improving efficiency and economic benefits. Guo, Xie, and Chen (2012) highlight the severe traffic issues in China's megacities and emphasize the need for underground logistics in major urban centers. They also propose potential application areas for underground logistics, identifying traffic congestion, limited urban space, and energy and environmental constraints as key drivers and research trends for the development of underground container transport.

The UCLS, seen as an innovative solution to urban traffic congestion and land resource shortages, has gained significant attention. Research provides a clear understanding of its development, trends, and practical benefits. By analyzing keywords, authors, and cited references, it highlights key research dynamics and guides future directions. Literature review also helps assess the system's real-world impact on improving transport efficiency, easing traffic congestion, and reducing pollution. Additionally, learning from global experiences promotes international academic exchange and accelerates the global research and application of underground container logistics. In short, literature analysis offers valuable insights for understanding, innovating, and supporting the UCLS.

3. Problem Description and Methodology

This research paper aims to address two key questions in the fields of logistics and urban freight transport. The first question focuses on a literature visualization process, which systematically reviews existing studies on ULS and UCLS. Through this process, the study seeks to unravel the complexities of these systems, offering a global perspective on research networks, identifying emerging trends, and providing a comprehensive overview of advanced theories and practices in the field. The second question delves into the practicality and investment potential of UCLS, employing case studies focused on the Shanghai Waigaoqiao Port area and leveraging cost-benefit models. This dual approach ensures a thorough evaluation of UCLS feasibility, incorporating real-world scenarios and economic factors to furnish decision support and risk assessment for stakeholders engaged in the implementation of UCLS.

In the initial step of this research, an extensive exploration of relevant literature was conducted using a comprehensive search strategy across multiple renowned platforms, including Web of Science (WOS) core, EI Village, and Scopus. The search formula employed for this comprehensive literature search was as follows:

TITTLE = *((“underground” OR (“train” OR “metro” OR “subway” OR “Urban Rail” or “Public transport”)) AND ((“logistics” OR “freight”) OR ((“goods” OR “freight” OR “cargo” OR “container”)*

AND ("transport" OR "delivery" OR "distribution" OR "movement" OR "shipment" OR "Transit" or "supply"))))

This formula was designed to capture publications that encompassed the intersection of underground transportation systems, specifically focusing on train, metro, urban rail, and public transport, with the dynamics of logistics and freight movements. The formula also considered various synonyms for key terms, ensuring a broad search scope. The search yielded a substantial result, totaling 1564 titles across the three platforms, with 543 titles from WOS core, 38 from EI, and 983 from Scopus. This comprehensive literature search lays the foundation for the subsequent phases of the study, providing a rich pool of resources for the systematic review and analysis of existing research on the mixture of underground transportation and logistics development.

The acquisition phase involved obtaining a total of 1564 titles from the literature search conducted across selected bibliographic database. Following the collection process, a rigorous screening procedure was implemented to refine the dataset. This process involved removing duplicates, which led to the exclusion of 451 titles. Additionally, 31 records were discarded due to incomplete information. As a result, 1,082 titles were retained for further evaluation.

Moving to the eligibility phase, the titles were scrutinized to ensure relevance to the research focus. A total of 582 titles were deemed irrelevant and were consequently excluded, leaving a refined dataset of 498 titles. Notably, this subset includes publications discussing various aspects, such as Public Transportation Networks, Underground Logistics Systems, Metro-ULS, and Underground Container Logistics Systems. This rigorous process of data acquisition, screening, and eligibility ensures that the dataset used for subsequent analysis is refined and relevant to the research objectives, thereby laying a solid foundation for a systematic literature analysis.

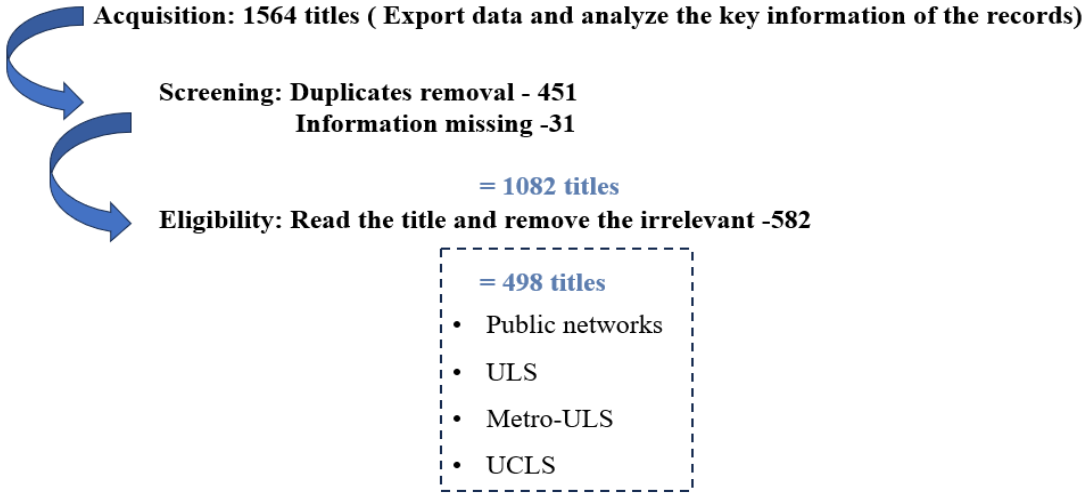

Figure 3. Relevant article screening process

Bibliometrix is a powerful tool specifically designed for bibliometric analysis within the R environment, providing rich functionality for data import, cleaning, quantitative analysis, and visualization. Its seamless integration with R enables researchers to efficiently handle literature data from diverse sources and gain insights into the development trends of a particular field using various methods. The visual tools within Bibliometrix intuitively present research findings, aiding them in delving deep into literature data to uncover crucial research insights. VOSviewer was then used to provide a visual network map to describe the relationships between keywords, authors and institutions. It facilitates keyword clustering to identify research trends and allows multidimensional exploration.

In the case analysis, a comparison was made between the current transportation mode in the Waigaoqiao Port Area and a new underground short-haul scheme. The current situation involves short-haul road transportation leading to road congestion and environmental pollution

between the port and nearby container yards. In contrast, the new scheme centralizes containers at a logistics hub in Jiading District and transports them to the port via underground channels, aiming to reduce truck traffic within the city, enhance transportation efficiency, and promote scaled operations. Through a cost-benefit analysis based on relevant data and energy-related formulas, the potential reduction in carbon emissions was also estimated, providing robust data support for improving transportation efficiency and mitigating environmental impact.

4. Research Results

Through a comprehensive analysis, we identified the publication cycles and trends related to the specified keywords by examining a substantial body of literature to discern patterns in their temporal distribution. This analysis has provided valuable insights, allowing us to better understand the dynamic changes within the research domain and laying a strong foundation for future studies. The results are presented in Figure 4.

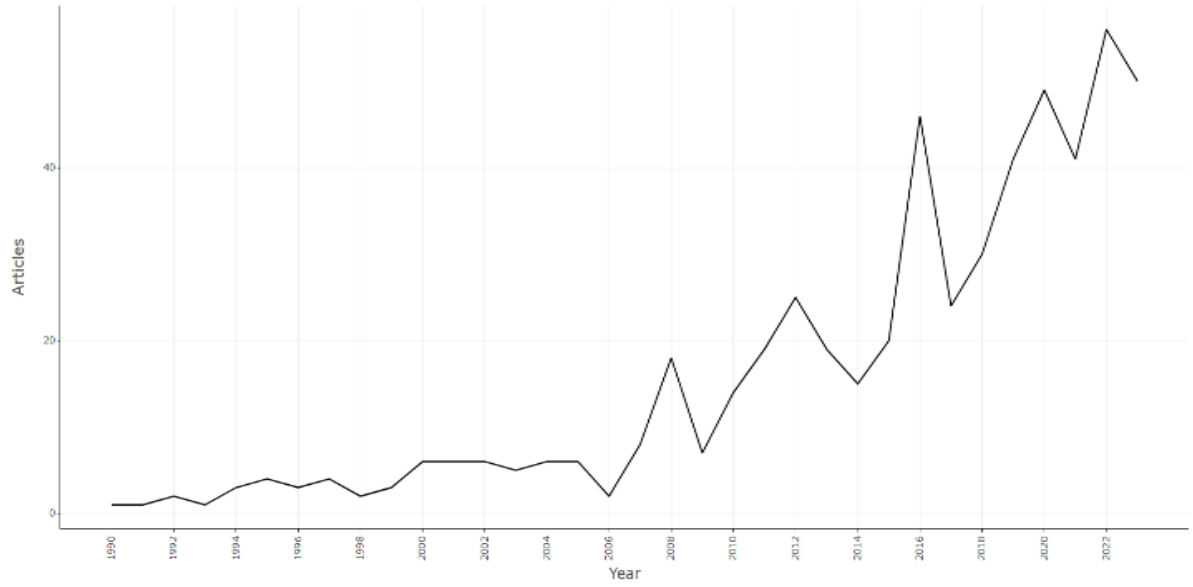

Figure 4. Annual Scientific Production

This result indicates that concepts related to underground logistics first emerged in 1990. Since 2006, a clear upward trend suggests significant development and growth in the field of underground logistics. This trend likely reflects an increasing focus on underground logistics in recent years, with a corresponding rise in related research. This observation provides a temporal reference for further exploration in the field of underground logistics and offers valuable insights for future research directions and strategic planning.

The Three-Field Plot is a valuable tool in literature analysis, providing a clear view of the relationships between authors, keywords, and articles. By illustrating author collaborations across different articles, it helps researchers understand collaboration patterns and frequencies. The plot also highlights keyword correlations, revealing key themes and domains within the literature. Additionally, it shows the distribution of articles across authors and keywords, offering a comprehensive view of the literature's structure. By analyzing the plot's trends, researchers can identify emerging patterns, such as the continued development of specific authors or keywords in certain thematic areas.

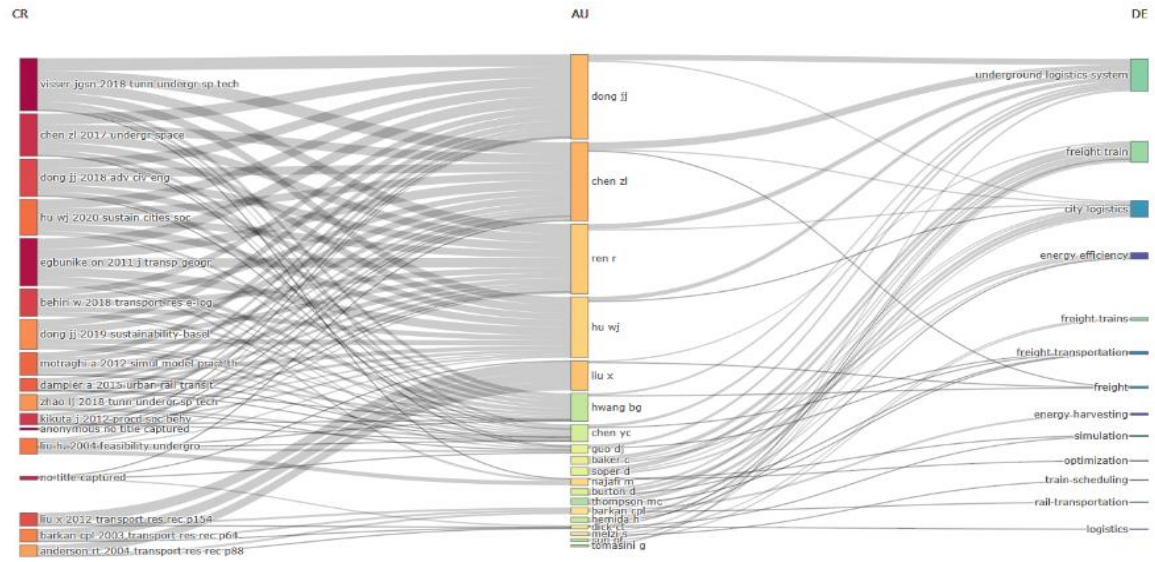

Figure 5. Three-Field Plot

Through the analysis of the results from the Three-Field Plot, we can observe several authors with relatively high weights, including Dong, jj, Chen, zl, Ren, r, and others. This indicates that these authors play significant roles in the research within the relevant field, and their contributions occupy a substantial portion of the literature. Notably, most researchers focus on topics such as Underground Logistics Systems, Freight Trains, and Urban Logistics. These prominent research directions likely mirror the current challenges and demands in the fields of logistics and transportation, providing valuable guidance for future research. Overall, the analysis of the Three-Field Plot results offers researchers a clear perspective, helping them better understand the relationships among different authors and keywords in the field and providing beneficial insights for further research and collaboration.

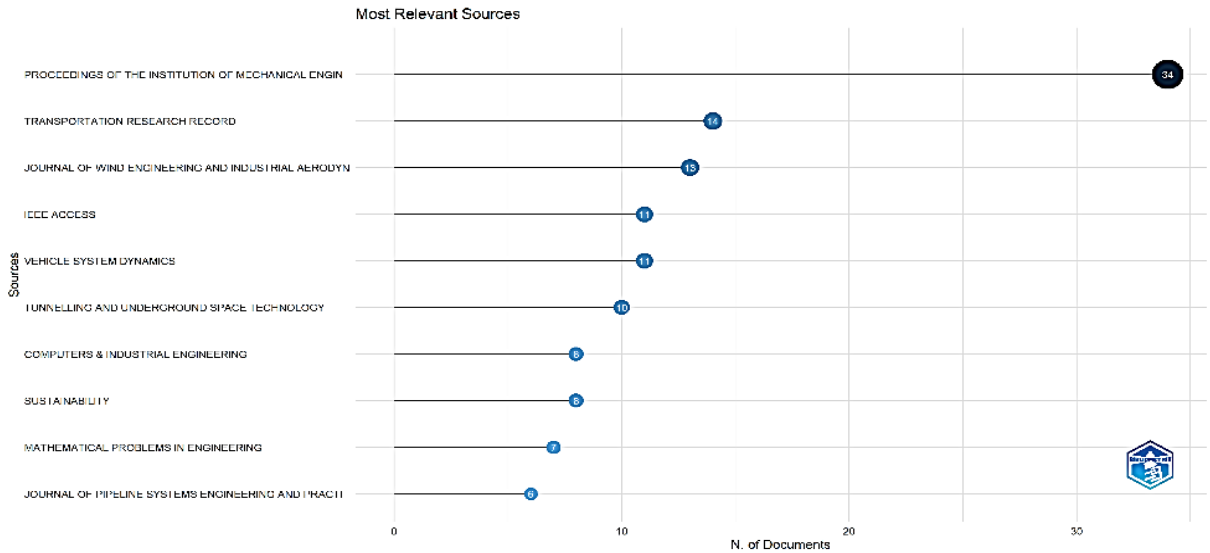

Figure 6. Most Relevant Sources

This citation list encompasses several key journal sources in the field of underground logistics systems. Topping the list is '*The Proceedings of the Institution of Mechanical Engineers*' with 34 citations, highlighting its significant standing in the realm of underground logistics research. Following closely is '*Transportation Research Record*' with 14 citations, though slightly less than the former, it still holds considerable importance. '*Journal of*

Wind Engineering and Industrial Aerodynamics' ranks third with 13 citations, further emphasizing its influence in the field of underground logistics systems research. Other journals such as '*IEEE Access*', '*Vehicle System Dynamics*', '*Tunnelling and Underground Space Technology*', '*Computer & Industrial Engineering*', and '*Sustainability*' also have significant citation counts in this list, indicating their popularity and widespread attention in the field of ULS. These major journal sources provide researchers with crucial resources to gain in-depth insights into the latest research and developments.

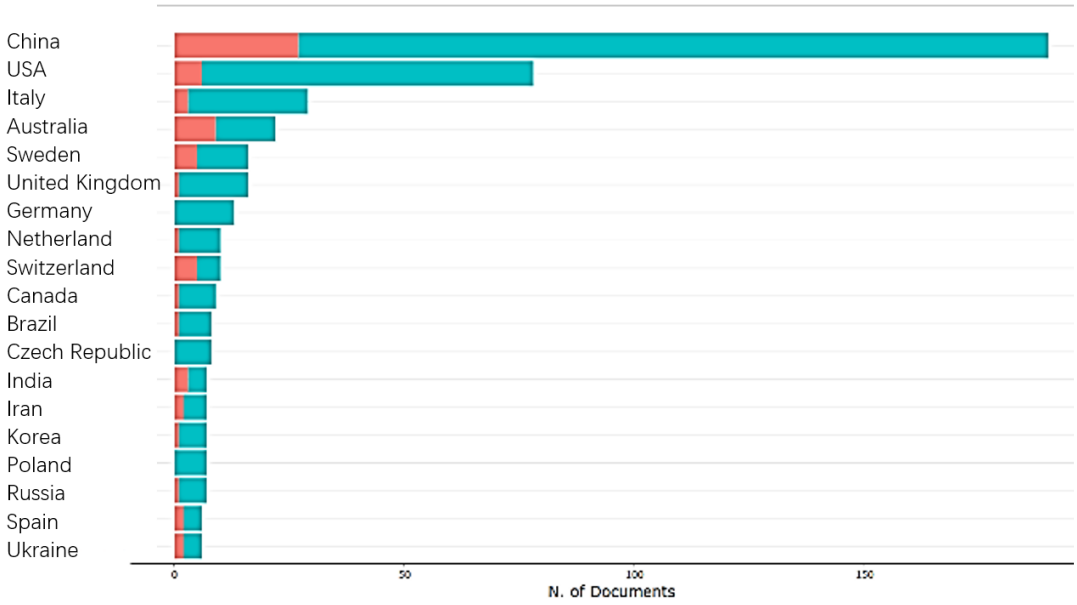

Figure 7. Corresponding Author's Countries

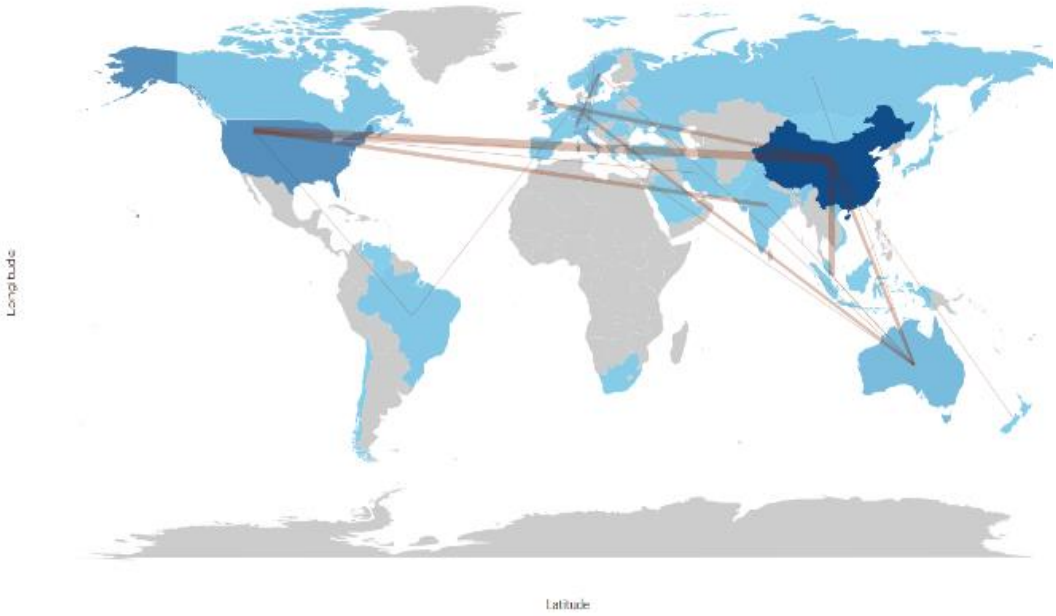

Figure 8. Analysis of cooperation between countries

Figure 7 illustrates the distribution of authors in the field of ULS by country. China takes a leading position in terms of the number of articles, with a total of 190 articles, including 163 Single Country Publications (SCPs) and 27 Multiple Country Publications (MCPs). The MCP ratio is 0.35, with an MCP frequency of 0.142. The United States closely follows with 78

articles, comprising 72 SCPs and 6 MCPs, resulting in an MCP ratio of 0.144 and an MCP frequency of 0.077. Additionally, 43 articles stem from collaborations between multiple countries. Italy's contribution is also noteworthy, with 29 articles, including 26 SCPs and 3 MCPs. These data reflect the collaboration and contributions among countries in the research of underground logistics systems, providing crucial information for a deeper understanding of international cooperation in this field.

The frequency analysis of keywords in this field provides insights into the primary focus areas of research in underground logistics systems. Taking "model," "optimization," and "design" as examples, they appear 47, 37, and 22 times, respectively, indicating a high level of attention to these topics in the literature. Additionally, keywords such as "system," "network," "freight transport," and "transport" demonstrate frequent discussions on these aspects in the literature. The occurrence of keywords like "railway," "models," and "simulation" also signifies a certain level of attention to these specific themes. The distribution of keyword frequencies provides researchers with clues for a comprehensive understanding of the research priorities and hotspots in the field of underground logistics systems, guiding future research directions and priority areas.

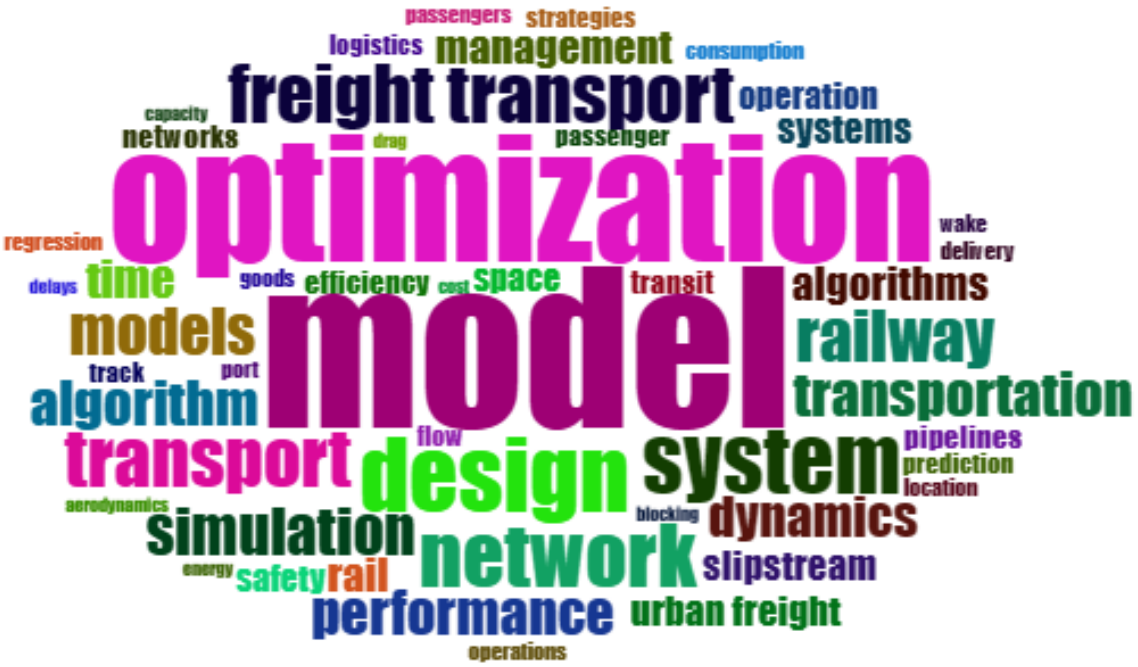

Figure 9. Keywords World Cloud

Next, use VOSviewer to perform Network, time series and density analysis for the keywords. Red is mainly associated with freight transport, the blue mainly includes keywords related to optimization, such as model, algorithm, etc.

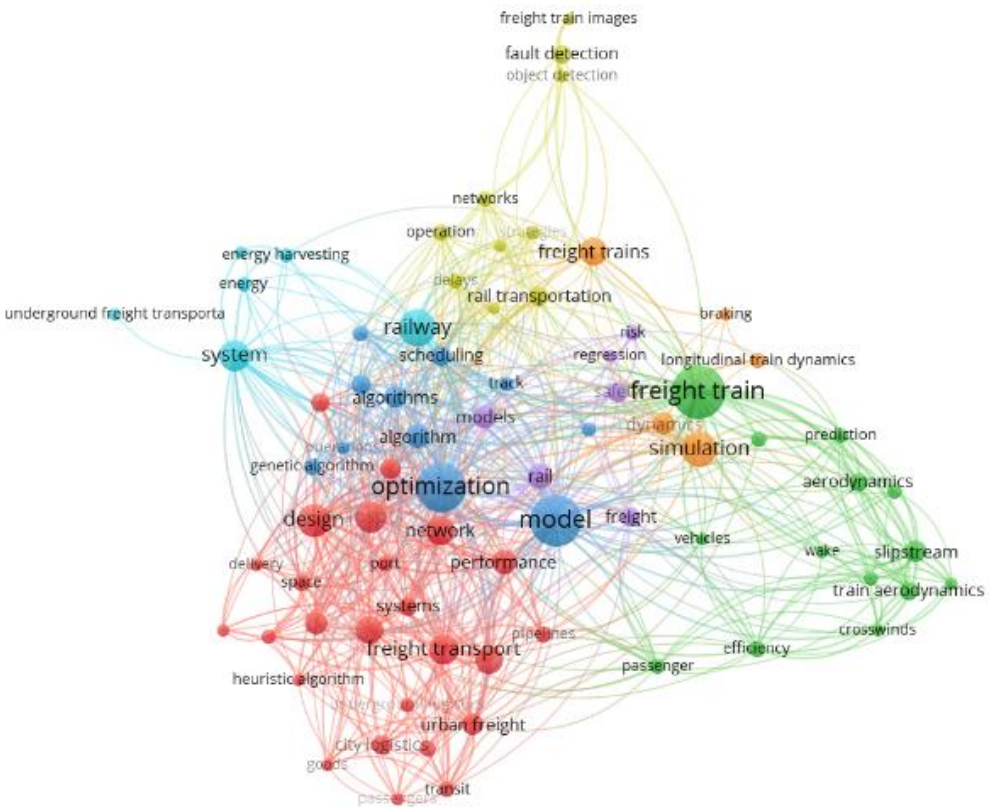

Figure 10. Keyword Co-occurrence Network

Figure 11, from blue to yellow, represents a time development in the direction of research. It can be seen that the latest research direction is to use genetic algorithms to solve problems in this field and focus on passengers and efficiency, which reflects the underground logistics system can carry out people and goods.

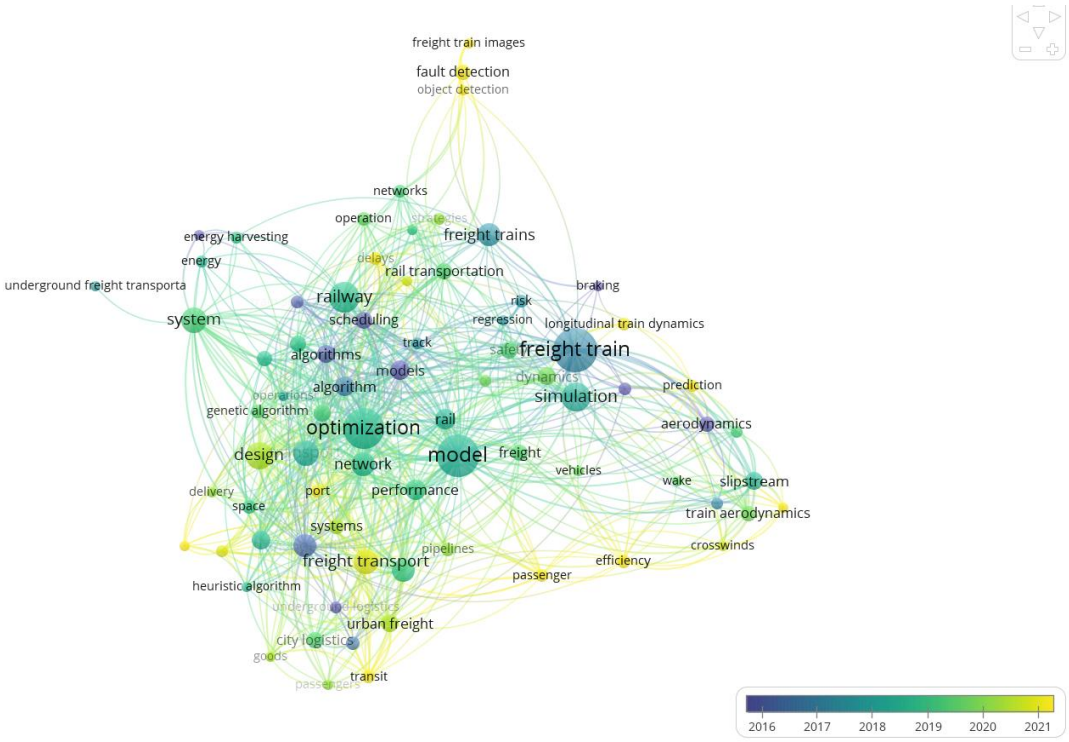

Figure 11. Keyword Co-occurrence time series analysis

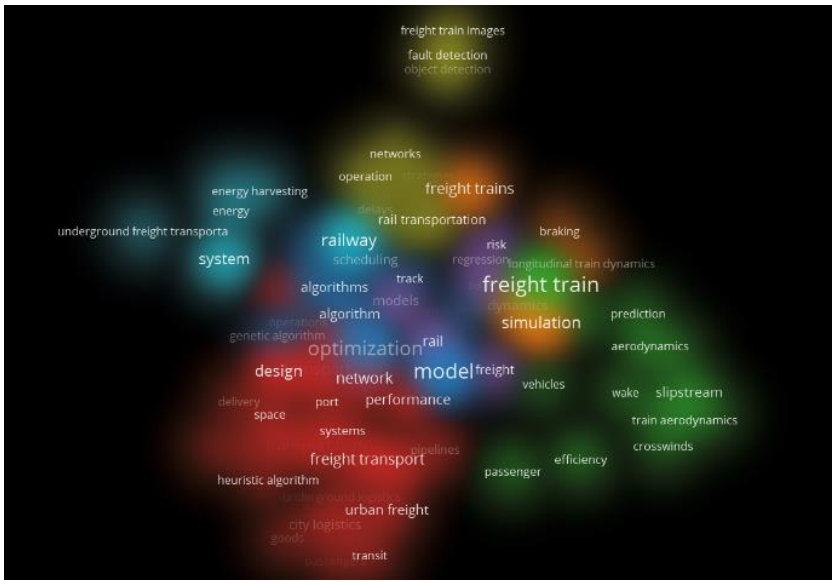

Figure 12. Keyword Co-occurrence density analysis

Keyword density analysis is a method for studying the structure and content of a text by identifying the distribution of keywords within it. It assists researchers in discovering themes, understanding focal points, pinpointing research hotspots, and facilitating text comparisons. This analysis provides a valuable tool for researchers to delve deeper into the text, guiding subsequent research directions. According to Figure 12, it is evident that keywords like 'Freight train', 'Model' and 'Optimization' exhibit higher research density.

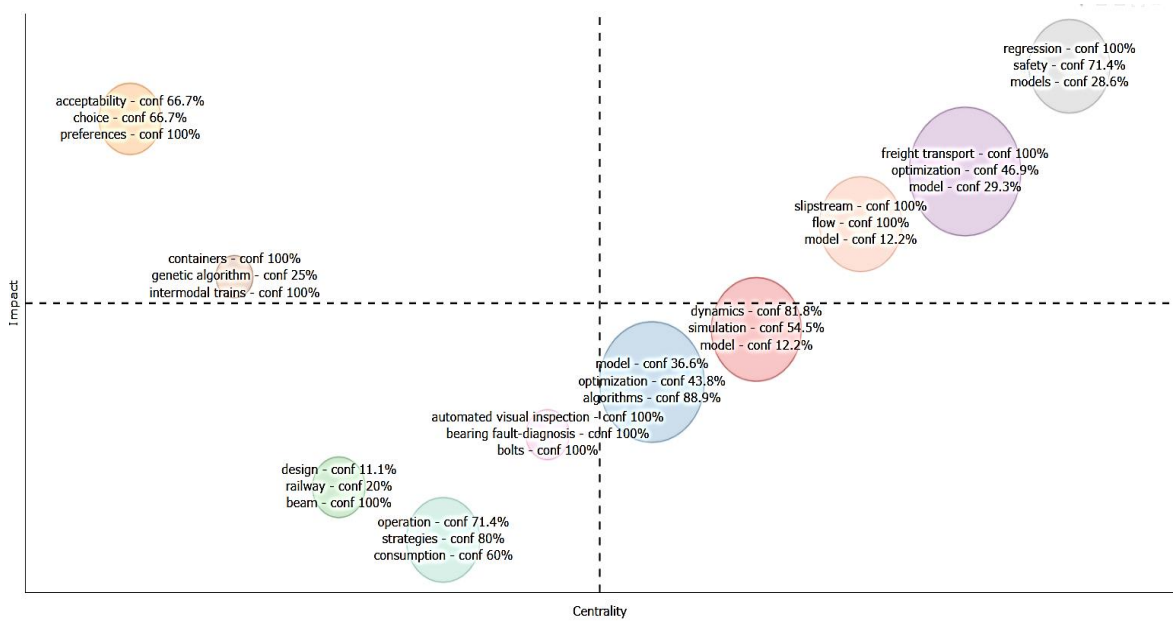

Figure 13. Coupling Clustering Analysis

The term "Clustering by Coupling" refers to a literature analysis technique that groups related keywords to reveal underlying themes and concepts within a research field. This method helps identify key topics, understand concept associations, and map the field structure, thereby guiding future research. By visually clustering keywords, researchers can easily grasp the central themes in study, simplifying complex information. In essence, clustering by coupling serves as a valuable tool for gaining deep insights into literature topics and directing subsequent research efforts. Figure 13 illustrates related keywords in ULS, with a significant

focus on primary research methodologies. Due to limited practical implementation, most researchers rely on modeling, simulation, and dynamic optimization methods to explore relevant issues. In addition to software analysis of the articles, we also conducted in-depth reading and outlined the development context, as depicted in Figure 14.

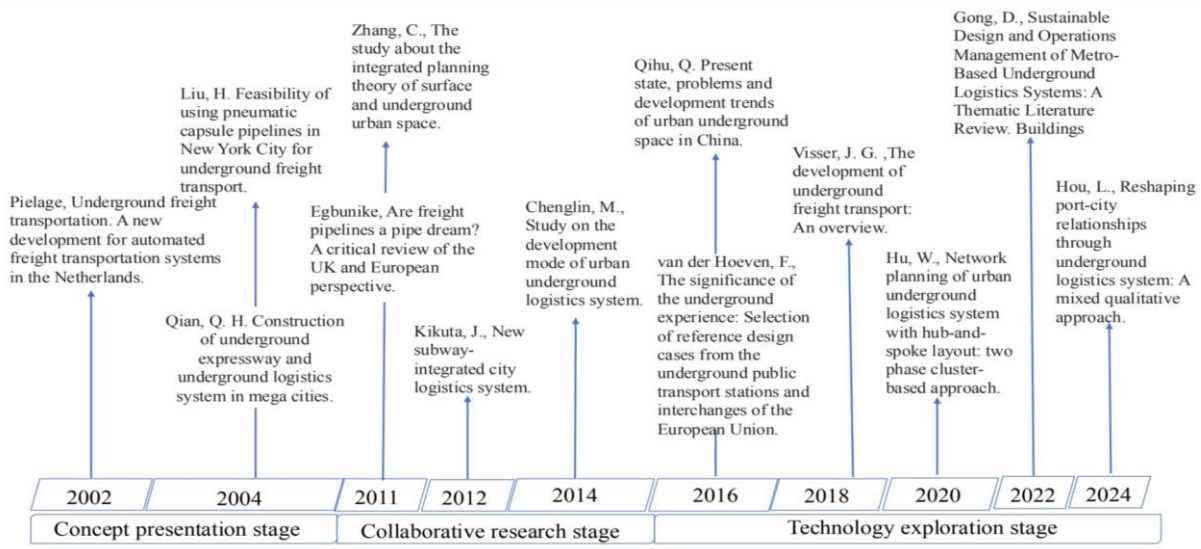

Figure 14. Review the development process of ULS

In summary, the evolution of research in this field has traversed distinct phases. In the initial conceptual phase, attention was dedicated to foundational concepts such as UFT, ULS, Underground Space, and Innovative Transport. Exploring various implementation forms like Pneumatic Capsule Pipeline (PCP), Hydraulic Capsule Pipeline (HCP), Electromagnetic Capsule Pipeline (ECP), and Underground Container Transport provided insights into the practical applications of these concepts.

As collaboration became a key focus, the study identified the integration of ULS into modern metro systems as a novel research direction. This collaboration phase marked a shift towards practical implementation and collaborative development. Simultaneously, the technological exploration period unfolded, revealing a diverse set of methods employed for planning, location, optimization, and evaluation. Planning methods encompassed network planning, urban planning, facility design, vehicle routing, operational planning, and considerations for new cities and port districts. Location-focused methods included node location and allocation, multi-objective programming, and scheduled lines. Optimization methods featured genetic algorithms, mixed-integer programs, heuristic algorithms, time windows, and system dynamics. Finally, evaluation methods encompassed life-cycle cost analysis, sensitivity assessments, comprehensive feasibility evaluations, TOPSIS, and economic evaluations. This comprehensive approach has not only expanded the theoretical foundations of ULS but has also paved the way for practical applications and future advancements in the field.

5. Shanghai Waigaoqiao Port-Jiading District Case Study Analysis

The current situation involves short-haul road transportation between the port and nearby container yards in the Waigaoqiao Port Area, leading to road congestion and environmental pollution. To address this issue, an underpass short barge scheme has been proposed: Containers, which were previously scattered, are now centralized at the logistics hub in Jiading District before being transported to the port via underground channels. This helps reduce truck traffic within the city, improves efficiency, and promotes scaled transportation.

The proposed solution involves centralizing originally dispersed goods and entering the port through overland routes at the peripheral logistics hub. Subsequently, these goods are transported to the port via an underground channel, reducing the need for trucks to traverse through the city and achieving efficient, scaled transportation, thereby minimizing the impact on urban traffic and the environment.

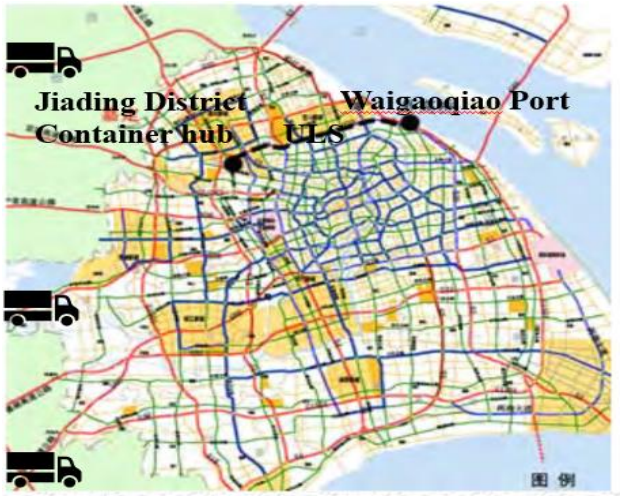

Figure 15. Waigaoqiao UCLS Project

According to the plan, the estimated cargo volume transported via land routes in the Shanghai Port is expected to range from 18 to 25 million TEU annually. Approximately half of this volume is attributed to the Waigaoqiao Port Area. Assuming that half of the containers are transported through the underground channel, the projected demand for underground container transportation is around 6 million TEU per year.

The proposed location for the scheme is a freight hub in Jiading District, where containers arriving from other cities are unloaded at the inland container station. Internal vehicles then transport the containers to the underground tunnel. Upon reaching the port area, the containers are lifted from the tunnel through vertical shafts using equipment such as gantry cranes and transported to the storage yard. Finally, internal vehicles shuttle the containers to the vessels.

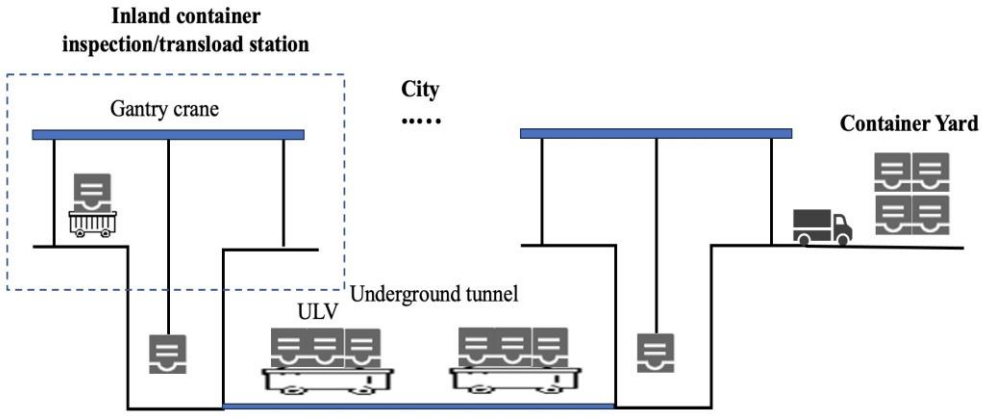

Figure 16. Underground container collection and distribution system

The Jiading freight hub shares similar functional layout features with the Waigaoqiao Port Area and can be considered an inland extension of the Waigaoqiao Port Area through the underground channel. The scheme's implementation requires the construction of a 30-kilometer-long shield tunnel, with a total cost estimate ranging from 8.5 to 9 billion yuan, including almost 800 million yuan for equipment.

The annual operating expenses are 660 million yuan (operating cost of 110 yuan/TEU), with annual operating revenue of 1.02 billion yuan (charging based on the current overland transportation cost of 170 yuan/TEU). Taking into account the time value of money (annual interest rate of 6%, 30-year term with equal

principal and interest repayment, requiring annual repayment of 650 million yuan), the annual loss is 290 million yuan.

Table 1. Comparison of container logistics cost between land and underground

	Land Transport	**UCLS**
Deadweight	2TEU	2TEU
Unit energy consumption	40 L diesel / 100km	37 kj / ton/km
Unit price of energy	Diesel:7 yuan per liter	Industrial electricity price:1yuan/kwh
Energy cost	140 yuan	20 yuan
Labor cost	100 yuan	50 yuan
Maintenance cost	70 yuan	35 yuan
Depreciation	60 yuan	20 yuan
other	20 yuan (Highway toll)	80 yuan (Transfer fee)
Total transportation cost	390 yuan	200 yuan

After the implementation of the plan, it can release road resources with a bidirectional capacity of four lanes. The energy consumption is reduced by 42 million liters of diesel, equivalent to about 60,000 tons of standard coal, resulting in an annual savings of fuel costs of up to 300 million yuan. This reduction corresponds to approximately 420,000 tons of carbon dioxide emissions per year. Additionally, it has the potential to enhance the environmental quality and land utilization value in the northern region of Shanghai.

However, it is crucial to note that while the peripheral logistics park is situated away from the city center with relatively ample land conditions, it may bring about new congestion and environmental pollution in the area. Assessing the pros and cons of the port's extended functionality and striking a balance between the interests of the port city and the transfer city requires coordination at a higher level.

6. Conclusion and Prospect

This paper provides an overview of the background and literature related to the ULS. Visual and summary analyses were conducted on the literature, leading to the following main conclusions from the research:

Due to the limited number of papers on the UCLS, the literature collection scope was expanded to include ULS, Metro-ULS, and other relevant underground logistics areas. Regarding quantity, research in this field is steadily increasing in academia, primarily focusing on countries such as China, the United States, and Australia. Relevance ranking was applied to journals and authors contributing to research in this field.

Next, VOSviewer was utilized for network, time series, and density analyses of keywords. The results indicate that 'optimization', 'simulation', and 'freight train' are the main keywords. Over time, the research methods in this field have gradually shifted towards advanced approaches such as system design, modeling, and simulation. The focus has evolved from simple freight transportation to integrated passenger and freight transportation. Coupled clustering is then applied to classify and visualize keywords with high similarity. Finally, the common citation relationships among authors and cooperation relationships among countries were identified. This provides a better understanding of the current status and trends in research in this field.

Next, through an intensive reading of key articles, a timeline analysis was conducted, revealing three distinct stages in the development of this field. The first stage is the conceptualization phase, which summarizes relevant guiding principles, implementation forms, and practical significance. The second stage is the collaborative research phase, identifying the trend of integrating ULS with modern metro systems. Finally, in the phase of technological exploration, four common categories of research problems were identified: planning, positioning, optimization, and

evaluation. Common methodologies employed in addressing these issues were also summarized.

Finally, a detailed presentation of the actual planning case for the Waigaoqiao Port to Jiading District in Shanghai is provided, including a comprehensive scheme introduction, benefit-cost calculation, and a rough estimate of its potential impact on alleviating traffic congestion and environmental pollution. Additionally, the advantages and disadvantages of the UCLS are highlighted.

Lastly, this research still has certain limitations, including insufficiently comprehensive early-stage literature collection that may impact subsequent literature analysis results. The visualization of literature is also not as intuitive and specific. Additionally, in the analysis of relevant cases, there is a lack of updated and more specific data, which hinders the provision of a comprehensive assessment. Consequently, it is challenging to offer well-founded recommendations and planning for the future development of the Underground Container Logistics System.

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