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Review

New Development Direction of Underground Logistics from the Perspective of Public Transport: A Systematic Review Based on Scientometrics

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Abstract: Research on the underground logistics system (ULS) has been carried out for nearly 30 years, but the description of the global research network, research trends, and the discussion of advanced theories and practices have not been systematically reviewed so far. The concept of public freight has expanded a new development direction: metro-based underground logistics system (M-ULS). The purpose of this paper is to analyze this new model by taking underground logistics and public freight as the research object. We performed statistical analyses of 222 references and constructed three kinds of visualized bibliographic information experiments for regional collaboration, authorship collaboration, and keywords co-occurrence. Based on the scientometrics results, the evolution path of the literature evolution was drawn. We used cluster-analysis-based taxonomy to structure the recent relevant literature. According to the comprehensive review, the research stays in the theoretical research stage, mainly focusing on system concept and planning, traffic organization, and network operation. There is still a lack of discussion on engineering quantification and application implementation. Finally, this study highlights some brief ideas, discussions, and potential suggestions for future research. This bibliometric research is expected to provide researchers and practitioners with a panoramic description and in-depth understanding of ULS and M-ULS research.

Keywords: underground logistics system; public transport; metro; literature review; scientometrics analysis; thematic analysis

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1. Introduction

Urban freight accounts for an increasing proportion of urban transport tasks, and is very important to the operation of the city [1]. Traditional logistics not only cannot meet the increasing urban freight demand, but also bring a huge burden to urban development. Scholars put forward the concept of "underground logistic system" (ULS) in the 1990s [2]. As an advanced intelligent transport system, a ULS can effectively ensure the efficiency, reliability, and sustainability of urban logistics distribution [3]. However, a ULS is a complex system involving many disciplines, such as above-ground and underground connection, logistics and engineering, construction, and management. Research progress is slow due to the huge investment, vague income, and lack of forward-looking theory.

A ULS project is huge and difficult to realize in a short time. The scheme of using a public passenger transport system to carry out freight service has become another way out for the sustainable development of urban freight. QiHu Qian, academician of the Chinese Academy of engineering, pointed out that the construction of a new smart city needs to include the vigorous development of green transport and green urban infrastructure characterized by a metro-based rail transit system and an urban underground logistics system. Savelsbergh et al. [4] pointed out that the biggest opportunity of urban logistics in the future lies in the design of an integrated service network of public transport and urban freight. Based on the above considerations, Chen et al. [5] proposed the concept of metro-based underground logistics (M-ULS) from the perspective of saving social resources.

Obviously, the development of ULS and public transport can enlighten and lead M-ULS. However, considering the time of publication and the number of papers, the existing research is outdated and incomplete. At the same time, it is difficult to integrate many research directions and build a complete knowledge structure. Therefore, an objective and quantitative study of the overall progress of ULS and public transport has important theoretical and practical significance for the implementation and application of M-ULS.

The intent of this article is to enable researchers to quickly understand and intervene in ULS and M-ULS through tabular description. In more detail, in this paper we want to answer the following questions:

- Can we find out the current international research status, hot spots, and research trends of ULS, public transport, and M-ULS?
- Can we organize the papers in a taxonomy and highlight the research mainstreams and future directions?
- Can we see any lack in current frameworks in the literature, in terms of current trends and future paths?

To answer our research questions, we structured this paper as follows. Sections 2 and 3 detail the six scientometrics experiments designed to track and analyze theoretically the evolution of the research field: (I) publication year and journals, (II) countries, organizations, and authors, and (III) literature keyword clustering and research topics. In Section 4, a cluster-analysis-based taxonomy is established to structure the recent relevant literature. Section 5 identifies the current research gaps and agenda. Section 6 summarizes the major findings and limitations.

2. Materials and Methods

Based on retrospective research, this study systematically investigated the academic development of global ULS, public transport, and M-ULS research by using the methods of scientific econometric analysis and scientific map. Scientometrics analysis is a quantitative tactic that can enhance the visual and logical perception of systematic review outcomes by assessing, clustering, and mapping the quality and the relevance of articles through mathematical models and algorithms [6]. Scientific knowledge map is an important method of scientific and technological measurement. It takes a certain knowledge field as the research object and shows the relationship between its internal scientific knowledge and the overall development process and structure. It can directly, clearly, and vividly interpret the dynamic evolution, development trend, research progress, and frontier hotspots of this knowledge domain through visualization technology. CiteSpace [7] is widely used by researchers in various fields because of its powerful function, good visualization effect, and rich layout. This method has been widely used in many academic fields [8], such as sustainable transport [9], environmental science [10], urban logistics [11], and waste management [12].

2.1. Overview of Review Protocol

Figure 1 presents the three-stage schematic process of this study. The research framework is organized as follows: In the first stage, a comprehensive material retrieval was carried out, followed by the setting of criteria to select literature, and finally, data synthesis was conducted. After an overview of indexed documents, the bibliographic network visualization and quantitative analysis were completed in Stage 2, where three branches of scientometrics experiments were designed and performed. In the third stage, three themes were discussed separately based on the scientometrics results. Finally, gaps and research findings were summarized.

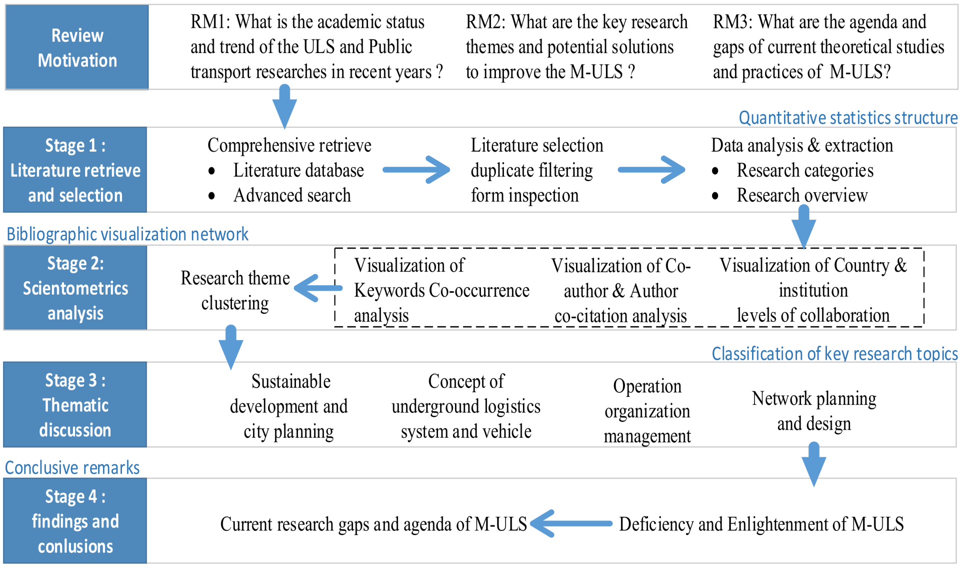


Figure 1. Systematic protocol of reviewing literature.

2.2. Literature Retrieval and Selection

Taking Web of Science (WOS) core, Engineering Village (EI) and Scopus as data sources, we selected advanced retrieval methods to search the literature from January 1990 to July 2021. In order to ensure the quality of literature, the document type was limited to research journal article and proceedings paper. Using the following advanced search statements: TITLE ((“underground” OR (“train$” OR “metro$” OR “subway$” OR “Urban Rail” or “Public transport”)) AND ((“logistics” OR “freight”) OR ((“goods” OR “freight” OR “cargo”) AND (“transport” OR “transport” OR “delivery” OR “distribution” OR “movement” OR “shipment” OR “Transit” or “supply”)))), 1239 records were obtained.

We conducted three rounds of data screening on the original data, and finally retained 222 qualified records focused on three modules. The process of literature collection and screening is shown in Figure 2. A total of 429 duplicate records were removed in the first round of screening. The second round removed 29 records with incomplete literature information, such as lack of author information, literature sources, or abstracts. In the third round, the titles and abstracts were checked one by one, and 559 references unrelated to the research topic, including mechanical structure and transportation organization of intercity heavy rail freight trains and others, were removed as shown in Table 1.

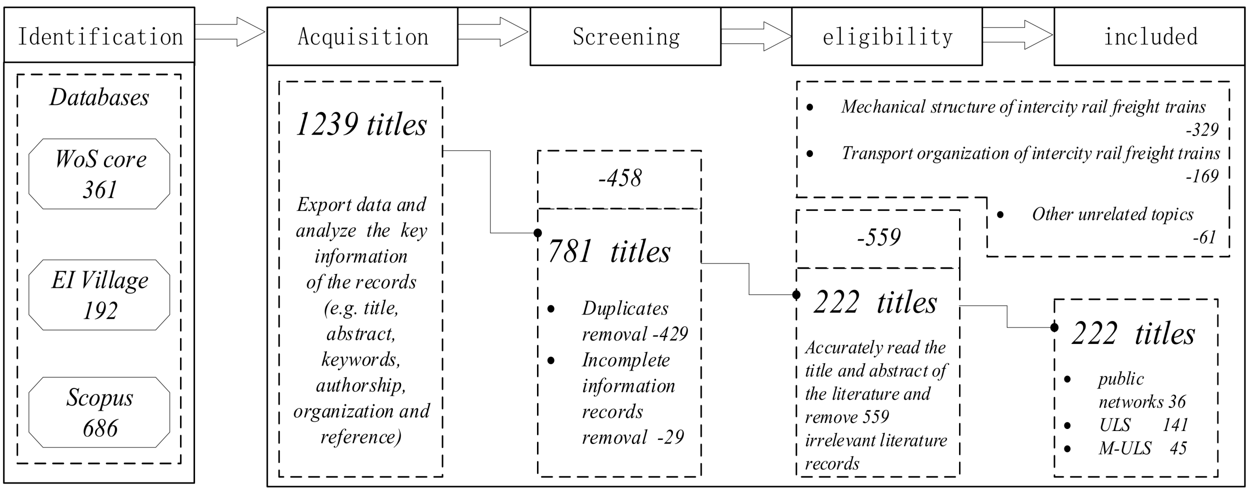


Figure 2. Flowchart of data collection.

Table 1. References unrelated to the research topic.

Mechanical Structure 329		Transportation Organization 169	
Deleted Topics	**Count**	**Deleted Topics**	**Count**
Freight train dynamics	96	Optimization of freight train operation	77
Energy saving of freight train	25	Freight trains formation and dispatching	54
Automatic control of freight train	20	Train operation safety	10
Freight train derailment and fault analysis	36	Transportation efficiency and cost	8
Train braking control	45	Freight forecast	5
Train load	4	Separation of passenger and freight	3
Freight train Speed	11	Multi−transport	5
Automatic detection of freight train	52	Train delay	3
Train noise and vibration	40	Freight yard operation	4
Other unrelated topics 61			
Driver sleep	2	Freight train location and recognition	4
Retraction	2	Transportation of dangerous goods	2
Literature unrelated to freight transport	23	Related to freight transport and not easy to classify	28

2.3. Overview of Selected Literature

The literature review portfolio contains 145 journal articles and 77 proceedings. Articles were included in 77 journals. Figure 3 shows the count of articles published in journals with IF higher than 3.0. The proceedings were included in 56 international conferences. Table 2 lists the three academic conferences with high influence. Papers in these journals and conferences are focused on.

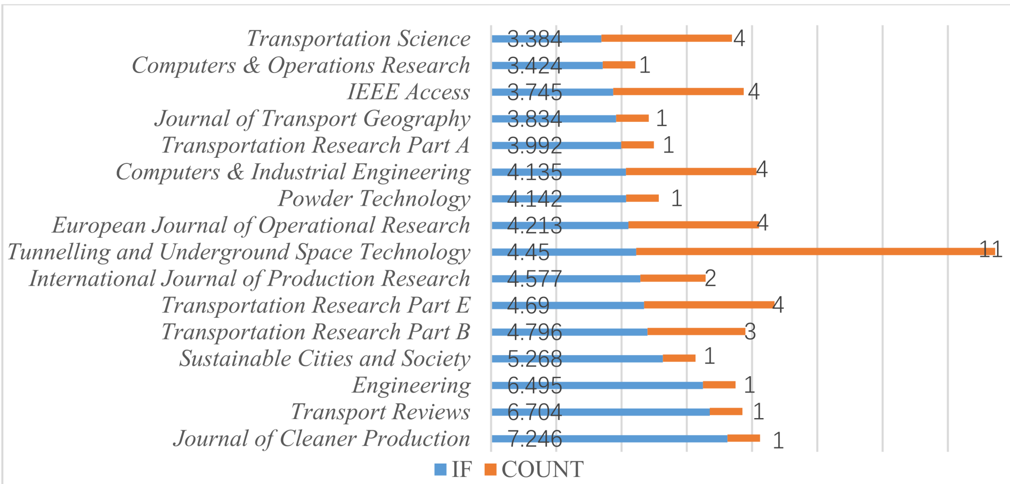


Figure 3. Rank of journals with high impact factors.

Table 2. Basic information of top 3 influential academic conferences.

Conference	Official Website	Count
International Society on Underground Freight Transportation (ISUFT)	www.isuft.org (accessed on 1 January 2022)	15
The American Society of Civil Engineers (ASCE) Pipelines Conference	www.asce.org (accessed on 1 January 2022)	7
Associated Research Centers for Urban Underground Space (ACUUS)	www.acuus.org (accessed on 1 January 2022)	5

Note: ISUFT proceedings were collected from the references of our literature review portfolio.

Figure 4 displays the number of papers published annually from 1996 to 2021 in the portfolio. Obviously, research on ULS and M-ULS was virtually stagnant until 2009, and relevant research has increased significantly year by year since 2016. In addition, after 2015, with the in-depth study of the concept of urban logistics and public transport integration and the promotion of underground logistics research, the development of M-ULS collaborative operation research has been promoted. From the publication number and the recent discussed topics of ULS and M-ULS, it is evident that the public awareness, market acceptance, social demand, and real-world practice of underground logistics are undergoing a remarkable ascent.

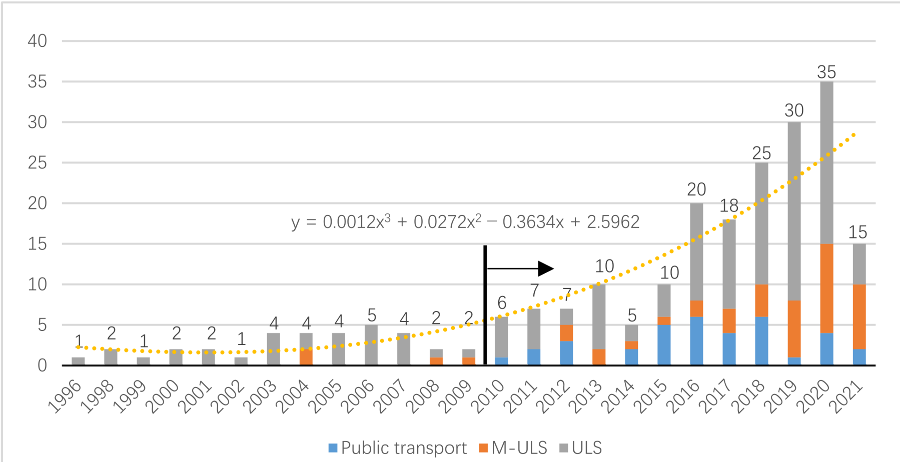


Figure 4. Chronological distribution of indexed documents.

3. Scientometrics Experiments and Analysis

Based on the citation analysis theory, we used the scientific text mining and information visualization software CiteSpace V (5.8.R1, http://cluster.cis.drexel.edu/~cchen/citespace/, accessed on 1 January 2022) to carry out three kinds of experiments, including countries/organizations collaboration, authorship collaboration, and keywords co-occurrence, with a total of five experiments. Before the experiment, we selected import/export under the data column to import the original data of EI village and Scopus and convert them into WOS format. The experimental parameter settings are shown in Table 3.

Table 3. Visual experiment parameter setting.

Parameter	Parameter Setting	Experiment
Time Slicing	From 1996 JAN To 2021 DEC # Years Per Slice 1	All Experiments
Text Source	Select: Title, Abstract, Author, Keywords (DE), Keywords Plus (ID)	
Node Type	Correspondingly select: Country, Author, Cite Author, Keyword	
Links	Strength: Cosine # Scope: Within Slices	
Selection Criteria	Select top 10% of most cited or occurred items from each slice	3, 4, 5, 6
	Select top 100% of most cited or occurred items from each slice	1, 2
Pruning	Pathfinder # Pruning the merged network	1, 2, 3(a)
	Minimum Spanning Tree # Pruning the merged network	3(b), 4, 5, 6

Note: Keywords (DE) (keywords given by the author); Keywords Plus (ID) (database additional keywords).

In the visual network, a node represents a specific bibliographic information type, while link describes the co-citation or collaboration between these nodes. The size of the node or label indicates the occurring frequency. The color changes of nodes and wires reflect the temporal distribution of literature. Nodes with a purple rim have higher centrality scores, indicating important relationships among large clusters they link [13]. Two metrics, the mean silhouette (S) and the modularity (Q), are used to reveal the "overall structural properties" of the network. A higher S value indicates a better matching degree between this node and its generic clustering, while a higher Q denotes a higher dispersion degree of the merged network [14]. Generally, Q > 0.3 means that the divided community structure is significant; S > 0.5 means clustering is reasonable.

3.1. Countries/Organizations Collaboration Experiments

CiteSpace provides two levels of regional scientific cooperation analysis, namely, institutional cooperation and national cooperation network. A visual network (as shown in Figure 5) representing the "country" category contains 33 nodes and 22 links. The number of relevant research papers in China (89) far exceeds that in other countries, the count of citations in the United States (272) is the highest, and the year of publication in Germany (1972) is the earliest. In addition, the Netherlands is also an influential country, with the highest average citation rate (12.69 times per article). From the perspective of network connection, China and the United States are important network nodes (centrality exceeds 0.1). There is almost no cooperative relationship among other countries. The international cooperation of research is obviously insufficient.

Figure 5. Experiment 1: Analysis of regional collaboration network.

A total of 161 institutions appeared in the selected articles, of which China (62) had the largest number of institutions, accounting for 38.51% of the total, followed by Germany (12), with only 7.45%. This paper focused on the analysis of 8 national institutions with strong influence, and created statistics on academic institutions and application-oriented companies to evaluate the actual construction and application of ULS in various countries, as shown in Table 4. Germany's application-oriented companies account for the highest proportion (41.67%), followed by the Netherlands (33.33%), which is consistent with the actual construction and promotion of ULS.

Table 4. Distribution of research institutions in main research countries.

Country	Total of Inst.	Num. of Academic Inst.	Num. of Application Co.	Percentage of Application Co.	Total Freq.
China	62	53	9	14.52%	176
Germany	12	7	5	41.67%	16
USA	9	7	2	22.22%	33
Singapore	6	5	1	16.67%	11
Netherlands	6	4	2	33.33%	23
Canada	5	5	0	0.00%	7
UK	4	4	0	0.00%	9
Belgium	1	1	0	0.00%	5

3.2. Authorship Collaboration Experiments

3.2.1. Co-Author Network

According to the 222 bibliographic authorship, an initial co-author network with 428 nodes and 788 links was generated. To facilitate the analysis of the cooperation network, the node position was adjusted and the minor nodes with less than 2 publications were weakened. Figure 6 shows 17 research teams. Cheng Zhilong and Mohsen Shahandashti, who are the top 2 prolific authors, form three closed-loop research teams. These teams cover the top 10 prolific authors and their studies have played the most important role in promoting the research on the subject, as shown in Table 5.

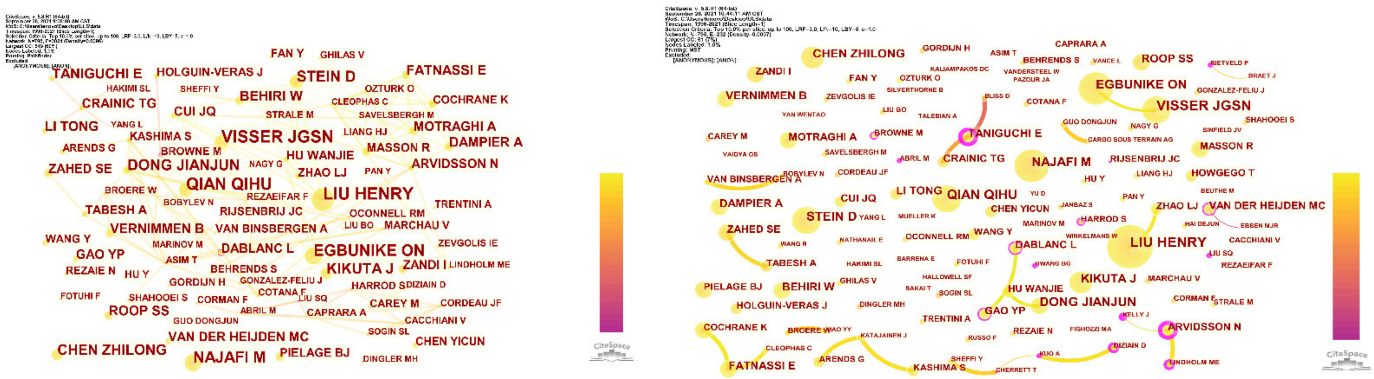
Figure 6. Experiment 2: Analysis of co-author network.

Table 5. Lead author team.

NO.	Scholar	Institution	Count	Country
1	Qihu Qian Zhilong Cheng DongJun Guo	Army Engineering University of PLA	19 19 8	China China China
2	Zhilong Cheng	Army Engineering University of PLA	19	China
	JianJun Dong Rui Ren	Nanjing Tech University	15 13	China China
	B HWANG	National University of Singapore	8	China
	WanJie Hu	Nanjing Tech University/Beijing Tech University	8	China
3	S Mohsen M NAJAFI Sirwan Shahooei Siamak Ardekani	University of Texas at Austin	16 15 7 7	USA USA USA USA

3.2.2. Author Co-Citation Network

In order to highlight the important authors in the research field, the cited author experiment took separate measures to complete pruning of the merged network. The author co-citation network with 795 nodes and the minor nodes with less than 5 citations were weakened. In Figure 7, the left figure uses Pathfinder to show a more complete network, the right uses minimum spanning tree to show the more closely related nodes. It is easy to see that Niklas Arvidsson (centrality = 0.55, Sweden), Eiichi Taniguchi (centrality = 0.49, Japan), and James Kelly (centrality = 0.46, UK) have a thick purple rim, indicating their work served as a bridge between different authors and communities. Larger nodes indicate authors whose work has been widely recognized and who play a fundamental role in promoting the ULS research. The top 10 highest cited authors are listed in Table 6.



(a) (b)

Figure 7. Experiment 3: Analysis of Author co-citation network. (**a**) Experiment 3(a); (**b**) Experiment 3(b).

Table 6. Rank of top 10 highest cited authors.

Scholar	Institution	Count	Country
Visser Jgsn	Delft University of Technology	35	Netherlands
Liu Henry	Freight Pipeline Company	34	USA
QiHu Qian	Chinese Academy of Engineering Army Engineering University of PLA	31	China
Egbunike ON	Cardiff University	26	UK
Najafi Mohammad	University of Texas at Austin	26	USA
JianJun Dong	Nanjing Tech University	23	China
Stein Dietrich	WG Pipeline Construction Maintenance Ruhr-University Bochum, Bochum	23	Germany
Jun Kikuta	Docon, Atsubetsu-ku, Sapporo	21	Japan
ZhiLong Chen	Army Engineering University of PLA	20	China
Eiichi Taniguchi	Kyoto University	17	Japan

3.3. Keywords Co-Occurrence Experiments

Keywords co-occurrence analysis is a method to study the development trend and research hotspot of a field by extracting keywords or subject terms and analyzing the distribution of their occurrence frequency. Two experiments were carried out in the co-occurrence analysis: keywords co-occurrence and bursts terms analysis. The keywords analyzed included original keywords offered by authors in their articles, and extended keywords based on the subject classification of journal or database. The bursts analyzed included extracted terms from the article title, keywords, supplementary keywords, and abstract.

Co-Occurrence Keywords

In the visualization process, 89 terms with similar meanings were merged, such as “transportation” and “transport”, and “critical problem” and “key link”. In order to facilitate the cluster analysis of common words, 23 words representing place names were excluded. A chronological network consisting of 398 nodes and 190 links reflecting the co-occurred keywords was built, as shown in Figure 8. The value of modularity and mean silhouette resulted in Q = 0.7454, S = 0.8806, and harmonic mean (Q, S) = 0.8073. The values of Q and S are ideal, indicating that the threshold setting of experiment is reasonable. The top 10 high-frequency keywords are “freight”, “underground logistics system”, “logistics”, “traffic congestion”, “transport”, “underground freight transport”, “pipeline”, “urban transport”, “city logistics”, and “cost”. Additionally, the five nodes that scored high in centrality for the purple rim are “freight” (centrality = 0.63), “logistics” (centrality = 0.42), “city logistics” (centrality = 0.39), “underground logistics system” (centrality = 0.34), and “cost” (centrality = 0.33). These keywords play a crucial role in connecting major branches of knowledge.

Keyword clustering analysis is an exploratory data mining technology. Its main function is to identify and classify keywords in a certain field. CiteSpace was used to cluster closely related keywords through the log likelihood ratio (LLR) algorithm. CiteSpace automatically gives each keyword a value through the algorithm, and the keyword with the largest median in the same cluster will be selected as the label word of the category. If the timeline button is selected, CiteSpace will set each node in the corresponding position according to the cluster to which the node belongs (coordinate vertical axis) and the published time (coordinate horizontal axis), so as to generate a timeline view. In the timeline map, the same cluster is arranged close to the same horizontal line, so it can intuitively outline the relationship between clusters and the historical span of literature in a cluster. Figure 9 presents the timeline map of 17 noticeable clusters automatically output by CiteSpace. The detailed classification results are given in Table 7. The cluster size represents the number of discrete keywords. In addition, in order to facilitate the formation of thematic discussion, 17 cluster tags were divided into three thematic groups.

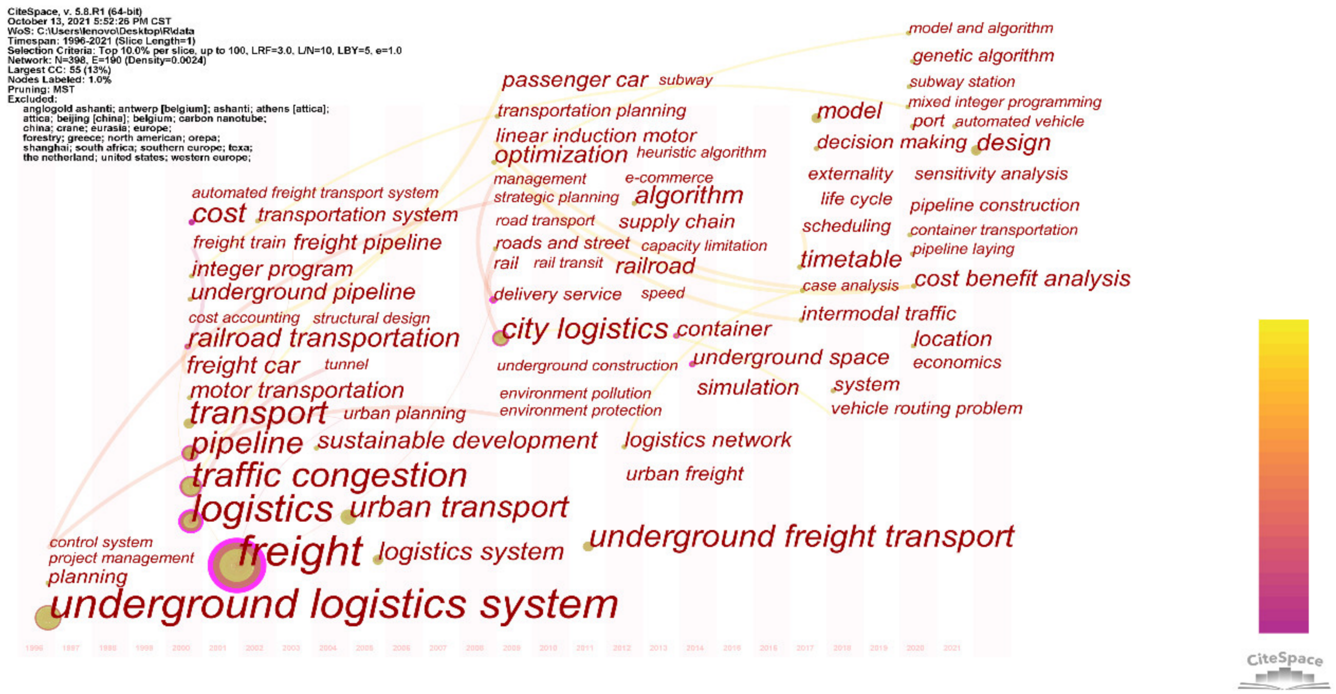


Figure 8. Experiment 4: Time zone distribution analysis of co-occurrence keywords.

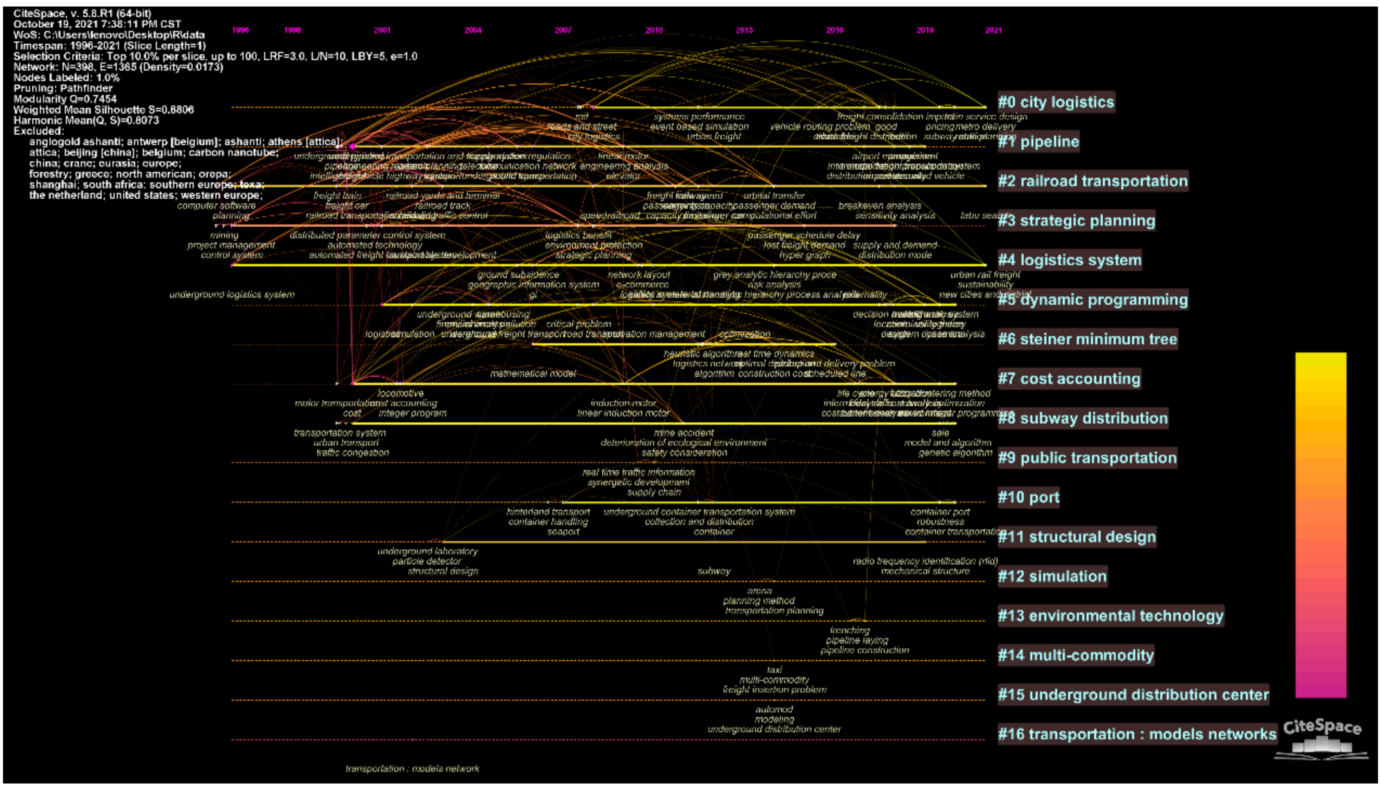


Figure 9. Experiment 5: Timeline clustering analysis of co-occurrence keywords.

Table 7. Categories of keyword clusters.

Topic Group	Cluster ID	Size	Silhouette	Mean Year	Cluster Label (LLR)
G1: Urban underground logistics system and planing	0	15	0.889	2014	city logistics
	11	4	0.945	2006	structural design
	13	3	0.969	2017	environmental technology
	15	1	1	2014	underground distribution center
	4	10	0.983	2010	logistics system
G2: Design and implementation of transportation organization research	1	19	0.793	2008	pipeline
	2	18	0.919	2009	railroad transportation
	8	8	0.98	2009	subway distribution
	9	2	0.985	2010	public transportation
	10	6	0.986	2014	port
	14	1	1	2014	multi-commodity
G3: Network structure and operation optimization	3	11	0.909	2004	strategic planning
	5	18	0.745	2013	dynamic programming
	6	8	0.979	2012	Steiner minimum tree
	7	14	0.838	2009	cost accounting
	12	2	1	2014	simulation
	16	1	0.936	2002	transportation: models networks

The research frontier emphasizes the new trend and mutation characteristics of scientific development [15]. Therefore, it is more suitable to track the frontier of discipline research with the help of surged topical terms high-frequency subject words [7]. We used CiteSpace to set burst terms, select terms as node type, and adjust the minimum duration and γ parameters in burstness. Table 8 lists the top 20 bursts terms.

Table 8. Experiment 6: Analysis of strongest citation bursts terms (top 20).

Terms	Strength	Duration	Terms	Strength	Duration
underground freight transport	4.9821	2016–2019	propulsion system	2.4866	2019–2019
underground logistics system	4.309	2019–2021	capacity limitation	2.3815	2020–2021
freight trains	3.5602	2015–2015	intermodal terminals	2.3712	2018–2019
passenger trains	3.4485	2014–2015	real-world simulation	2.3404	2019–2021
freight	3.0426	2015–2017	mathematical model	2.2197	2013–2016
city logistics	2.9897	2020–2021	urban freight distribution	2.1804	2017–2018
civil engineers	2.9638	2018–2019	sensitivity analysis	1.9836	2020–2021
auto freight transport system	2.7677	2018–2019	new mode	1.9494	2019–2021
carrying freight	2.5933	2016–2017	underground space	1.9456	2016–2016
underground pipelines	2.5484	2016–2017	engineering geology	1.9256	2013–2013

The top 2 strongest bursts terms are “underground freight transport” and “underground logistics system”, which is consistent with the time division of time cluster analysis. The sudden period of these bursts terms has obvious time division, and “underground logistics system” is gradually used as a special noun in the research of underground freight transport. “Freight trains”, “passenger trains”, and “intermodal terminals” indicate that ULS operation needs to be combined with various urban transportation modes. Using urban railway to realize urban passenger and freight collaborative transport is an alternative to the ULS operation. “Civil engineers”, “engineering geography”, “automated freight transport system”, “propulsion system”, “capacity limitation”, “real world simulation”, and “mathematical model” respectively point out the relevant technical support research fields for the development of ULS in the future from the aspects of building structure, mechanical power, and operation optimization.

3.4. Literature Evolution Path

Combined with the time zone distribution of keywords and the publication of the paper, the evolution path and development is divided into three stages: concept proposal stage, collaborative operation stage, and key technology research stage. We comprehensively considered the source, author, citation, and other factors of the literature, combed the keywords and key literature of key nodes in chronological order, and drew the evolution route of underground transportation research, as shown in Figure 10.

From the 1990s to 2009 was the stage of ULS concept proposal and system design. The traffic congestion and environmental damage brought by the process of urbanization exacerbated the burden of urban freight [16]. The traditional form of urban freight could no longer meet the logistics needs. Expansion and improvement of existing infrastructure for the various transport modalities were not always possible [17]. The form of small batch and scattered freight needed to be innovated, and it was particularly important to build a sustainable and integrated urban transport system in a planned way [18]. Many classic logistics systems were designed, such as OLS-ASH [17], CargoCap [18], pneumatic capsule pipeline (PCP) [19], and underground container transport system (UCTS) [16].

2009–2015 was the preliminary development stage of the research on the coordinated operation of ULS and public transport. The development of E-commerce had further exacerbated the contradiction between urban freight supply and demand [20]. The disadvantages of environmental pollution brought by traditional road transport continued to show. The concept of developing underground freight as an alternative to road transport had been gradually recognized by society [21]. At the same time, people had also noticed the difficulty of underground logistics construction [22], the affluence and imbalance of urban passenger transport resources [23], and the advantages of railway transport [24]. These three factors inspired a new idea of coordinated operation of urban underground logistics and urban subway [25].

From 2015 to 2021, the research entered the stage of technology quantitative exploration. With the recognition of ULS, the research began to be closely related to urban logistics and dynamic planning, and gradually moved to the application research stage. The research topics focus on underground space development and management [26,27], pipe network site selection and construction [28,29], cost–benefit analysis [30–32], operation plan research [33,34], etc. The coordinated operation of urban underground logistics and urban subway has become a research hotspot. A series of studies were carried out on intermodal transport optimization of M-ULS, such as the station function design [35], station location [36], network planning [29,37], operation plan [38], and freight connection [39]. Related optimization algorithms were the mainstream of research. The concept of coordinated development of public transport and logistics [40,41] attracted scholars' attention, and relevant research on buses [42] and taxis [43] was also derived. In addition, the scheme research focused more specifically on the application of real areas. Guo et al. [44] summarized the implementation elements of building and planning underground logistics in new cities and districts in China. Fan et al. [45] and Hai et al. [46] planned the connection between the underground logistics system and the container port in Shanghai.

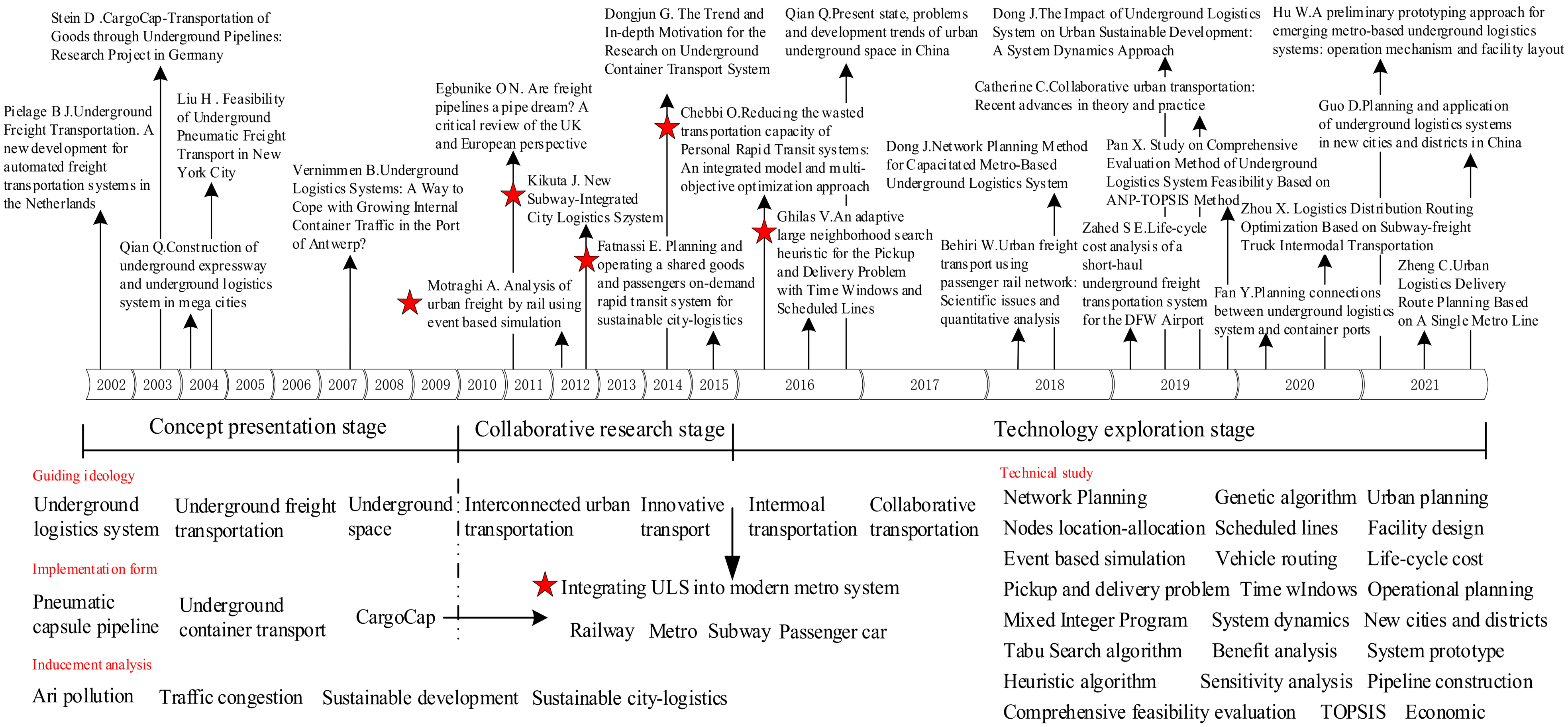


Figure 10. Evolution route of underground transport research.

4. Discussion

4.1. Taxonomy Construction

We followed the three-steps method to build the cluster-analysis-based taxonomy [47]. Based on the previous work, we briefly describe this process as follows:

- We began with the empirical analysis of a database of papers. The titles and abstracts were checked one by one, and those unrelated to the research topic were removed, as shown in Table 1.
- In the second stage, the information obtained in the first stage was clustered. CiteSpace was used to cluster closely related keywords through log likelihood ratio (LLR) algorithm, obtaining 17 noticeable clusters, as shown in Table 7.
- In the third stage, a mental concept of the cluster was envisioned by generating a name or label for the cluster, which was integrated into one of three research topics. Figure 11 depicts the result of our process and is structured in three levels of detail.

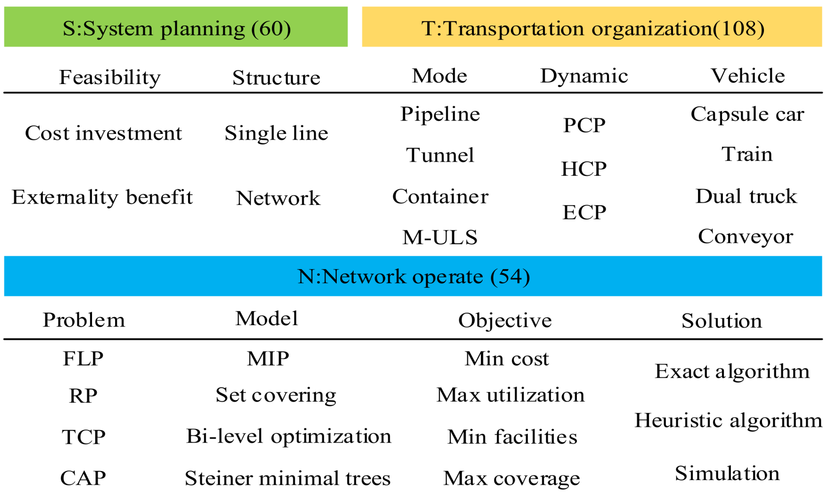


Figure 11. The knowledge taxonomy structure.

The rest of Chapter 4 provides a description of the objects and ranges for each axis and its category. The number of representative articles of each theme is included.

We reviewed the research objective of each study, and divided the studies into quantitative research, qualitative research, and applied research. Qualitative research includes overview, design, planning, etc.; quantitative research includes optimization, simulation, and evaluation; application research refers to the development of hardware and software for implementation, such as vehicle equipment, tunnel construction, and information system. Figure 12 shows the distribution in each part.

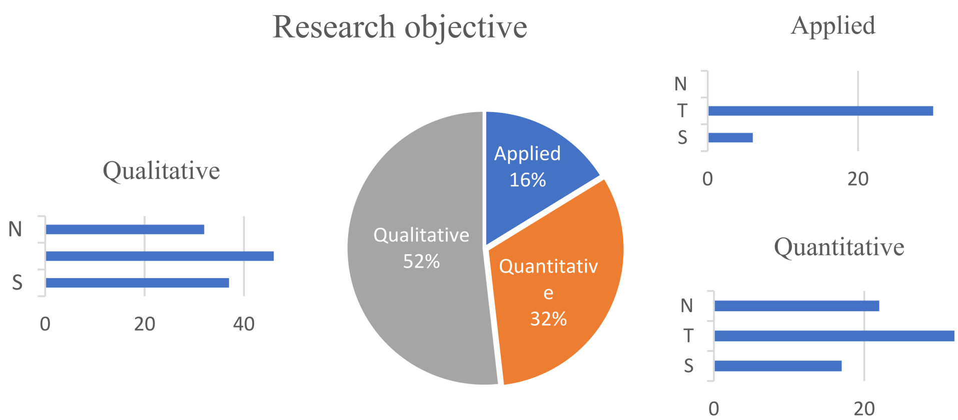


Figure 12. Distribution according to research objective.

Considering both the literature evolution path and the distribution of research objectives, although underground freight transportation has entered the stage of quantitative technology exploration, the proportion of applied research and engineering quantitative research is still small, especially the research on application and implementation.

4.2. Part 1 Urban Underground Logistics System and Planing

4.2.1. Research on ULS Concept

International research on ULS has been conducted for nearly 30 years, but it is still a relatively new expansion field [3]. Urban ULS is a fully automated transport and supply system that uses clean energy vehicles to transport goods in closed spaces such as underground tunnels or pipelines in a separate or grouped manner, finally distributing the goods to each terminal [48,49]. These terminals include factories, business centers, and even residential areas [3]. From the research topics and relevant literature review of all ISUFT conferences, the problems involved range from the technical research of single pipeline transport to construction, design planning, integrated operation management, and other directions and fields. Underground logistics system has developed into a complex system integrating a modern logistics concept and operation mode.

4.2.2. Sustainable Underground Transportation System

The research shows that the implementation of ULS is of great significance to the sustainability of urban logistics. This can be summarized into the following four aspects: alleviate the pressure of urban transportation; improve the efficiency of urban logistics; improve the quality of living environment; integrate social resources. Liu et al. [19] and Qian [50] pointed out that urban ULS can reduce the dependence of freight on trucks, alleviate road and traffic congestion, and related environmental problems, such as air pollution and noise. Moreover, these environmental problems would be completely solved, because vehicle exhaust can be contained and treated within the tunnel system [51]. Shang et al. [52] calculated the three indicators of logistics volume, network efficiency, and negative effect under the condition of fixed demand, and verified the advantages of establishing the ULS on the existing route. Similarly, Hai et al. [46] proposed an empirical method, taking Shanghai Waigaoqiao port to Jiading as the study area. Dong et al. [30] studied the impact of four ULS network densities on the sustainable development of Beijing by using the system dynamics. The four representative indicators selected were average road network speed in peak hours, congestion loss, delivery travel time in peak hours, and truck PM emission. The results showed that the four indicators performed best under a high-density network, and the improvement rates were 28.1%, 28.0%, 45.45%, and 64.2%, respectively.

4.2.3. Urban Underground Logistics Planning

Interdisciplinary cooperation is one of the key success factors to ensure the realization of ULS. At present, there are two main planning ideas for ULS construction: one is to establish a complete urban underground logistics system, and the other is to establish an independent freight channel in key sections. Guo et al. [44] introduced the framework of ULS planning and implementation elements for the construction of new urban areas from a theoretical perspective. Lu et al. [53] focused on the example and gave the ULS planning scheme for the central area of Daqiao group in Jinan Development Zone. The University of Texas at Austin evaluated the ULS planning of key sections from the perspective of economic evaluation. It was also one of the few research institutions that considered construction cost. Rezaie et al. [49] recorded and summarized the feasibility study meeting of a ULS project construction. Participants put forward 26 key issues and 8 benefits of building the ULS, and planned two key lines. Zahed et al. [54] proposed a five-step life cycle benefit–cost analysis method for construction of a ULS. The method includes (1) developing ULS scenarios of different sizes (small, medium, and large) and routes (short-term and long-term), (2) determining life cycle cash flow, (3) calculating net present value, benefit–cost ratio, and internal rate of return, (4) sensitivity analysis, (5) breakeven analysis. Then, they used an example to verify that the implementation of a ULS is financially reasonable by taking the short-distance ULS of Dallas Fort Worth International Airport as an example [31]. In addition, the University of Texas also studied and compared the environmental impact assessment of ULS trenchless and cover excavation construction methods [55].

4.3. PART 2 Design and Implementation of Transportation Organization

4.3.1. Organizational Form and Dynamic System

At present, the freight organization forms of ULSs include underground capsule pipeline, tunnel, and container transport. Qian et al. [2] suggested that the models of underground logistics system be divided into three categories: pneumatic capsule pipeline (PCP), hydraulic capsule pipeline (HCP), and electromagnetic capsule pipeline (ECP). The research of Liu et al. [19] plays an important role in promoting the PCP system, and theirs was the first paper to focus on the concept, dynamic system, and empirical research of PCP. O'Connell et al. [56] and Asim and Mishra [57], respectively, gave design plans for capsule transport capsules of PCP and HCP. Due to some limitations with PCP and HCP, such as being without an auto navigation function [2], ECP was developed. Shahooei et al. [58] elaborated the operation principle of the power system and found a suitable propulsion system for the ULS—linear induction motor (LIM). The subsequent new ULS mostly uses electromagnetic power devices, and the ECP has gradually become a research hotspot.

4.3.2. Typical Transport Systems and Vehicle

With the deepening of the concept of sustainable development, the design of modern ULSs tends to be automated, rapid, and clean. Many countries have studied the feasibility of modern underground freight transport, and designed transport tools and transport systems. Typical pipeline designs include CargoCap and Mole Underground Freight Pipeline (MUFP); tunnel type designs include Dual Mode Truck (DMT), Cargo Sous Terrain (CST), and Ondergronds Logistiek System (OLS); container type designs include Freight Shuttle System (FSS) and Hyperloop. The locomotive forms and main parameters of the above ULS are shown in Table 9.

Table 9. Concept and main parameters of locomotive in underground logistics system.

System	Nation	Power	Cargo unit	Vehicle	Speed (km/h)	References
DMT	Japan	Hybrid vehicle	—	Truck	City:45 Intercity:100	[59]
FSS	USA	Electric	45ft Container	Locomotive	105	[60]
MUFP	UK	Electric	Tray $1 \times 1.2 \times 1.8$	Bulk	21	[61]
CargoCap	Germany	Electric Maglev	European tray $0.8 \times 1.2 \times 1.05$	Capsule car	36	[62]
Hyperloop	USA	Electric Maglev	Container, Pallet	Large cabin	1126	[63]
CST	Switzerland	Electric	Small package	Suspended conveyor	60	[64]
			Tray	AGV	30	
OLS-ASH	Netherlands	Electric	Tray	AGV	20–40	[65]

Note: AGV (automated guided vehicle).

4.3.3. Rail Transit Coordinated Transport

The ideal underground logistics system is an independent transport network that covers the whole city and is close to customers [66]. However, there are planning, technical, and political challenges in implementing underground freight transport. Visser [3] stressed that it is becoming more and more difficult to build tunnels or lay pipelines, because the available urban shallow underground space has been exhausted. Moreover, due to the long construction period [5] and high construction funds [66], it is difficult to make substantive progress. The metro network with developed urban rail transit can provide the system with the opportunity to realize comprehensive integration, simple project construction, and effective service delivery [66]. Moreover, it is also difficult to achieve uniformity or balance in space and time with the utilization of metro, as the vehicles and infrastructure are not fully utilized, especially during off-peak times or on some suburban lines. If the coordinated transport can be realized by relying on the surplus transport capacity of the urban metro and combining it with ULS, it would be an energy-saving, environmentally friendly, safe, and efficient local logistics mode [67].

M-ULS is a typical mixed transport mode [68]. Elbert and Rentschler [69] defined this mode as Freight on Transit, and divided it into the following three categories.

(1) Shared track: freight is transported by a separate vehicle that only shares with public transport infrastructure.
(2) Shared vehicles: freight is transported in separate trucks or additional trailers.
(3) Shared truck: freight and passenger are transported in the same truck or carriage.

In order to deeply study this new comprehensive system, referring to the classification of urban rail transit [24], our research scope includes not only metro system, but also suburban railway and tram. Table 10 lists 14 classic qualitative research cases searched from the references, which are briefly summarized from eight aspects: research type, track type, sharing mode, urban background, standardized transportation unit, last mile distribution, fright type, analysis content, and service range. Cases 1–12 are conceptual studies, half of them have been simulated from different aspects to quantify the practical effect of scheme implementation. Cases 13–14 are real cases. More than half of the cases made it clear that the vehicle was metro, and three cases generally attributed the carrying vehicle to urban rail transit, including metro, urban railway, and tram.

Nine cases identified the transport standard carrier unit, and the standardized transportation unit (STU) can improve cargo handling, thus helping to save time and cost [69].

As for the connection of the last kilometer distribution, some studies tend to integrate cargo bikes, E-trucks, and drones for joint distribution. Villa and Monzon [70] and Serafini et al. [71] proposed intelligent locker pick-up and delivery mode. Serafini et al. [71] focused on the public's willingness of this mode at the metro entrance. Kikuta et al. [25] conducted a pilot project to understand the options of Sapporo taxpayers.

In terms of research content, most researchers used simulation to study the external benefits of M-ULS, such as reducing congestion, accident, noise, greenhouse gas emission, and air pollution [70,72–74]. Zhou et al. [68] and Brice et al. [75] studied the train carrying capacity and dispatching plan of single-track transport by simulation. Hu et al. [73] and Kelly and Marinov [76] both proposed the organization form of metro freight. Kelly and Marinov [76] considered various innovative designs inside metro wagon to separate passengers and goods. Hu et al. [35] put forward the innovative concept of M-ULS prototype, and the research involved cooperation mechanism, transport strategy, delivery scheme, and station layout. Yubo et al. [66] determined the basic mode of delivery process and summarized the basic principles of planning and building urban rail transit lines. Lee and Kweon [77] and Wang and Deng [78], respectively, gave hardware design schemes for vehicle control device and logistics control management system in underground freight systems.

B2C and B2B were the main types of freight services. Urban rail transit provides a smooth network between logistics center and warehouse. It is also a fast track between suppliers and customers [66]. There are three other types of freight worth noting. Brice et al. [75] proposed a baggage transfer system. Zurich freight trams are used for waste collection [79]. Regue [74] also proposed a similar way of waste transport. Volkswagen Group usesthe existing passenger rail network of Dresden to transport auto parts [80].

Table 10. Case study of urban rail transit freight transport.

References	Type of Study	Track Type	Sharing	Background	STU	Last Mile	Freight Type	Analysis Content	Service Range
[70]	Case Study Simulation	Metro	Track Vehicle	Madrid, Spain	Container	Locker	B2C	Operating costs Externality benefits	Network
[68]	Case Study Simulation	Metro	Track Vehicle Wagon	Chengdu, China	Container Trolley	-	Parcel	Capacity CO_2 emissions	Single line
[66]	Desk Study	Urban rail transit	Vehicle	—	—	Bike Motorbike	B2B B2C	—	Network
[25]	Case Study	Metro	Wagon	Sapporo, Japan	Trolley	Vehicle	B2BB2C	Public satisfaction	Single line
[72]	Case Study	Trams and trains	—	Belgium	—	—	—	Externality benefits	Network
[73]	Case Study Simulation	Urban rail transit	Vehicle	Beijing, China	Standardized transport units	E-Vehicles Cargo-bikes Lockers	Parcel	Externality benefits	Network
[35]	Case Study Simulation	Metro	Track Vehicle	Beijing, China	Containers Pallets	E-Vehicles, cargo-bikes, Drones, Crowdsourcing	Parcel	Innovative concepts for M-ULS prototypes	Network
[76]	Case Study	Metro	Vehicle Wagon	Newcastle upon Tyne, UK	Wheeled boxes	Cargo bikes, Electric	—	Designs for the interior of the metro carriage	Single Line
[24]	Case Study Simulation	Urban rail transit	Track Vehicle	Newcastle upon Tyne, UK	Logistic boxes	Manual pick-up	B2B B2C	Scheduling	Network
[75]	Case Study Simulation	Metro	Track Vehicle	Newcastle upon Tyne, UK	Containers Cradles	Manual pick-up	Baggage	Capacity Scheduling	Single Line
[71]	Case Study	Metro	—	Rome, Italy	—	Locker	B2C	Underlying behavior	Network
[74]	Case Study	Tram	Track	Barcelona, Spain	—	Cross-docking facilities Perpendicular short side tracks	B2C Waste	Cost benefit analysis	Network
[80]	Review	Tram	Track	Dresden, Germany	Containers	—	Car parts	—	Single Line
[79]	Review	Tram	Track	Zurich, Switzerland	—	Manual pick-up	Waste	—	Network

These cases have confirmed the potential use of urban rail transit in urban logistics distribution, and the utilization of its excess capacity will also help to (I) reduce operating costs, (II) meet delivery deadlines and improve customer service for urban needs, and (III) reduce current externalities

In addition to the above 14 qualitative cases, there are 4 quantitative optimization studies on the operation scheme. Behiri et al. [34] identified relevant scientific issues at the strategic, tactical, and operational levels. Then, aiming at minimizing the total waiting time of all requirements at the departure station, studied the railway freight scheduling problem and established a mixed-integer program (MIP) model. Ozturk and Patrick [81] established two objective functions under known freight demand: minimizing the inventory level at the departure station and minimizing the total delay of goods delivery, and established two mixed integer models. Li et al. [82], balancing revenue and cost, proposed a mixed integer linear programming model aiming at maximizing the profit of freight service, and designed an iterative scheduling method to solve the model. Zheng et al. [38] established a path optimization model to minimize distribution costs based on a metro line. The model considered the capacity constraints of ground distribution vehicles, soft customer time window, and vehicle routing time window. Their research provides support for the operation of metro freight from different direction, and lays a foundation for the M-ULS network operation.

4.4. PART 3 Network Structure and Operation Optimization

The network planning and design of ULS refers to the design of nodes, channels, routes, and corresponding feature parameters [48] with the goal of improving the comprehensive efficiency of the freight network based the conditions of meeting a certain service capacity, customer needs, investment budget, and common security [83]. This work not only directly affects the operation efficiency, but also affects the project investment and the economic and social benefits of the ULS. Qihu Qian team proposed five steps for the construction of a ULS in Beijing, including urban geographic information analysis, exploitable area analysis, node selection, network layout scheme, and optimization evaluation [84,85]. Siamak Ardekani team took Houston port [83] and Dallas Fort Worth International Airport [48] as background cases to establish the optimization model of a ULS network and illustrate its advantages.

The research focuses on five aspects: network structure analysis, facility location, rout, terminal connection, and competitive allocation. Table 11 lists the basic information of the collected literature. There are 13 ULS network cases, 8 M-ULS cases, and 3 UCTS cases. In addition, Chinese scholars also put forward underground emergency logistics system (UELS) [86] model, which expands the application form of underground logistics.

Table 11. Cases of network planning and design.

References	Problem	Mode	Model	Solution	Background	Factor	Objective	Network Classification
[87]	FLP	ULS	Set covering model. 0–1 MIP	Bat-inspired algorithm	Shanghai, China	Demand, construction and fixed and distribution costs	Minimize number of logistics nodes and associated costs	Logistics center Distribution center.
[36]	FLP	MULS	Complex network P-median model	TOPSIS, AHP	Shanghai, China	Node importance index, demand, distance	Minimize distance between the demand and the metro freight hub	Metro freight hub
[88]	FLP	MULS	P-median model	Voronoi diagram, Shortest pathalgorithm	Nanjing, China	Infrastructure cost, distance, capacity limit, passenger impact cost, logistics cost	Minimize the transport costs	One Level
[89]	FLP	ULS	Set covering and Weighted set covering model	Iterative evolution	—	Congestion index, weighted distance, freight volume	Minimize the number of facilities	Tow Level
[90]	FLP	ULS	ISM	—	—	Geology, freight flow, traffic impedance, service level, cost and other 27 factors	Analyze the relationship between influencing factors	—
[91]	FLP	ULS	Bi-level optimization model	Heuristic algorithm	—	Operating and fixed and transport cost, demand, capacity limit	Upper level: minimize logistics cost Lower level: minimize the cost per customer	One Level
[86]	FLP	UELS	Multi-objective model	Iterative evolution	Shanghai, China	Congestion index, rescue distance, rescue time, special nodes, covered areas	Minimize rescue time and station construction cost	One Level
[92]	RP	ULS	Steiner minimal trees model	PGSA	—	—	Algorithm comparison	One Level
[93]	RP	ULS	MIP	SA	—	Cost, capacity limit, congestion index	Minimize cost	Tow Level
[28]	RP	ULS	Evaluating Model Dynamic programming	Uncertainty graph Improved SA	Nanjing, China	Cost, uncertainty index	Minimize total path length	One Level

Table 11. *Cont.*

References	Problem	Mode	Model	Solution	Background	Factor	Objective	Network Classification
[94]	LRP	ULS	Bi-objective linear MIP Linear MIP	GA-MPSO Floyd–Warshall	Beijing, China	Path construction and transport and node activated cost, capacity limit, path utilization	Minimize costs Maximize system utilization	Distribution centers Ground terminal
[95]	LRP	ULS	MIP	GA-FCM, DFS-FCM; DA	Nanjing, China		Minimize costs	
[37]	LAP	MULS	Evaluating model MIP	E-TOPSIS, Heuristic algorithm	Nanjing, China	Service capacity, freight flow, regional accessibility, distance	Minimize number of facilities Minimize costs	Metro freight hub Ground terminal
[96]	LARP	MULS	Fuzzy stochastic programming MIP	Binary chaotic GA Exact algorithm	—	Demand, cost, capacity limit,	Minimize construction and operation cost Maximize system utilization	
[97]	LARP	MULS	Entropy TOPSIS model MIP	Exact algorithm Immune clonal selection algorithm Floyd–Warshall	Nanjing, China	Single freight flow, order priority, capacity limit, cost regional accessibility	Minimize set coverage Minimize construction and operation cost	Metro freight hub Ground terminal
[98]	LRP	ULS	Multi-objective model.	GA	China	Capacity limits, price, node construction and pipeline construction and transport and transfer cost.	Minimize cost	Disposal center Transfer station
[29]	LRP	ULS	Set covering modelMIP	Fuzzy clustering	Nanjing, China	Capacity limit, congestion and construction and transport cost	Minimize number of facilities Minimize cost	Tow Level
[99]	LRP	MULS	E-TOPSIS Max-covering model	Greedy randomized adaptive search TS	Shanghai, China	Capacity limit, distance	Maximize coverage Minimize distribution distance	Tow Level

Table 11. *Cont.*

References	Problem	Mode	Model	Solution	Background	Factor	Objective	Network Classification
[100]	FLPTCP	MULS	MIP, Multi-assignment P-hub median and P-hub covering problem	Modified GA	Shanghai, China	Demand, capacity limit, construction and operating costs	Minimize cost	Ground terminal
[39]	TCP	MULS	MIP	Modified GA	—	Metro surplus capacity, truck capacity, maximum driving distance, customer service time window	Minimize distribution distance	One Level
[101]	TCP	UCTS	Nonlinear MIP	Simulation	Shanghai, China	Waiting and arrival time, capacity limit, lifting cost	Minimize total cost of the crane and waiting cost of vehicle queuing	One Level
[102]	TCP	UCTS	0–1 planning model	Simulation	Shanghai, China	Investment and operating cost, time	Minimize cost	One Level
[45]	FLPTCP	UCTS	Robust optimization model	Simulation	Shanghai, China	Capacity limit, construction and transportation and management cost, uncertain container volume	Minimize cost	One Level
[103]	CAP	ULS	Nonlinear MIP Baumol–Wolfe model	Approximate iterative algorithm	—	Transport and loss cost, pipeline capacity, node service capacity	Minimize cost	Underground hub Ground terminal
[104]	CAP	ULS	Utility theory method Stochastic assignment model	K-shortest path routing algorithm	—	Travel speed, capacity limit of lines and nodes, departure frequency	Minimize generalized cost	One Level

4.4.1. Network Structure Analysis

The research on network structure remains at the level of qualitative research. In the literature searched, only Huang et al. [84] and Han [105] summarized the network characteristics of different frameworks and gave the steps of ULS network structure design. Influenced by the question F (construction of ULS network) of the 2017 China graduate mathematical modeling competition [106], most of the network forms are secondary hub and spoke underground logistics networks. Network node classification only focuses on the optimization process. When the demand point or supply point is known, they will not be included in the network classification node.

4.4.2. Facility Location Problem (FLP)

Generally, the objective function of the FLP is the minimum cost or the minimum node. The objective function is expressed as a combination of demand (or supply) quantity, cost, and distribution distance. There are four location models in the selected cases: set covering model, double-layer optimization model, p-median model, and fuzzy clustering. He et al. [87] and Ren et al. [89] established secondary underground logistics, and both of them determined primary logistics nodes by set covering model. Yan and Tan [91] established a double-layer optimization model. The upper-level programming minimizes the generalized logistics cost from the perspective of decision makers; the lower-level planning describes the selection behavior of customers, and the objective is to minimize the cost of each customer. The model breaks the traditional model that only considers the favorable factors of logistics providers. Yun et al. [90], based on the interpretative structural modeling method (ISM), analyzed the influence on network location with 27 influencing factors, and constructed a multilevel hierarchical structure model, which provides strong support for the fuzzy location and TOPSIS evaluation methods. Wei et al. [29] used fuzzy C-means clustering to minimize the sum of squared error between each sample and its clustering, and complete the classification of selected ULS nodes. This process includes a certain probability estimation process, which is suitable for the classification problem without clear boundary characteristics in reality. Zhao et al. [36] first used AHP and TOPSIS models to evaluate the importance of each metro station and selected alternative stations, and then used the p-median model to determine metro distribution stations in alternative stations. Zheng et al. [88] also used the p-median model, but compared with the previous study, the model comprehensively considered four factors: infrastructure cost, distance, capacity limit, passenger impact cost, and logistics factor cost, and was optimized by using Voronoi diagram.

4.4.3. Routing Problem (RP)

The routing planning problem usually establishes an MIP model to minimize the path construction investment. This kind of problem is a typical NP hard problem. Genetic algorithm (GA), ant colony optimization (ACO), particle swarm optimization (PSO), tabu search (TS), and simulated annealing (SA) are common algorithms [107]. Li and Wang [92] used Steiner minimum tree and found another way optimize the path by simulated plant growth algorithm (PGSA). Zhong et al. [28] proposed a dynamic programming model, which comprehensively uses the uncertainty graph and the improved SA. This model reflects the network construction progress and dynamic evolution process in the solution process, and is more in line with the network planning process in reality. The five papers of the JianJun Dong team should be paid attention to. They comprehensively considered the FLP, RP, and allocation problem, derived location-routing (LRP) and location-allocation-Routing (LARP) problems, expanding the research field. First, they designed a two-level ULS network considering the same influencing factors with the objectives of minimizing cost and maximizing network utilization [94,95]. Then, they used the method of combining fuzzy evaluation and mixed integer programming model to design the M-ULS network [37,93,94]. Ren et al. [97] and Hu et al. [96] considered path construction on the basis of the work of Dong et al. [37]. The three papers have the same background, but pay attention to different influencing factors, objective functions, and solving algorithms, which provides a powerful reference for network operation planning.

4.4.4. Terminal Connection Problem (TCP)

The TCP can be regarded as an extension of the multimodal transport problem from above ground to underground. Zhou et al. [39] studied routing optimization of subway–freight truck intermodal transportation. Ji et al. [100] evaluated M-ULS network performance from two perspectives: the number of hubs and the proportion of taxi drivers willing to carry packages. Fan et al. [45], Pan et al. [102], and Gao et al. [101] designed the terminal intermodal mode of a UCTS and planned the corresponding operation process. These three papers also provide guidance for the terminal freight stations in operation planning, layout, and transfer capacity evaluation. Gao et al. [101] established a multi service queuing optimization model based on container arrival time. Fan et al. [45] established a robust optimization model for the uncertainty of the number of containers, then proposed the internal layout scheme and the area calculation scheme. Pan et al. [102] proposed a simulation scheme for transport capacity evaluation.

4.4.5. Competitive Allocation Problem(CAP)

There are few references related to competitive allocation. The existing two papers focus on the impact of different influencing factors on the competitive allocation of surface and underground transport. Liu et al. [103] discussed the impact of pipeline capacity, node service capacity, unit loss cost, and cost proportion on allocation. Chen et al. [104] studied the effects of travel speed, departure frequency, and capacity constraints of lines and nodes on allocation based on random utility theory and random allocation model.

5. M-ULS Research Gaps and Agenda

The current research has made remarkable achievements in concept and planning layout. However, its development still stays in the theoretical research stage, and the research field fails to involve all aspects of actual operation. There is still a lack of discussion on engineering quantification and application implementation. We further explore the deficiencies and gaps of research from two aspects of theoretical research and application implementation, and give a panoramic description of the future research direction.

5.1. Theoretical Research

5.1.1. Large-Scale Simulation System

M-ULS is an uncertain comprehensive complex transportation system, and the corresponding simulation system is the basis of applied research. We believe that a crucial point for the relevance and utilization of simulation lies with the development of more detailed and flexible models, as well as a better integration of simulation and optimization. Simulation models will grow even larger and with more details when the results of the previous items become available [108]. Therefore, the development of new hardware and software high-performance computing architecture is also necessary.

5.1.2. Cost–Benefit Quantitative Research

An important factor restricting quantitative research is that it is difficult to objectively and accurately quantify the environmental and social benefits of the underground comprehensive transportation system. In other words, it is necessary to evaluate the cost-effectiveness of the whole life cycle of the underground transportation project. The papers of Siamak Ardekani team have important reference value. Clarifying project investors is the premise of quantifying cost-effectiveness. However, the question of who will invest and manage is also an urgent problem. Due to the publicity of metro transport, the government has the responsibility for decision-making and management, but private financing is also becoming an option, as the cases of Cargo Sous Terrain in Switzerland and Hyperloop in the USA show [3].

5.1.3. Market Competition and Game

M-ULS lacks research on the definition of appropriate goods, freight prediction, and pricing. As a new form of transportation, it is necessary to give a clear market positioning and game with other modes through reasonable price competition, so as to integrate into the increasingly mature and complete urban logistics market. In addition, the number, volume, and weight of appropriate goods are the basis for quantitative analysis, and their lack seriously restricts the management research of M-ULS. Therefore, it is necessary to fill the gap in the field of M-ULS market competition to meet the overall demand of urban freight.

5.1.4. Multimodal Transport Network Coupling

M-ULS is currently modeled and optimized as a separate system. This means that the coupling between M-ULS and urban freight network is not considered. There is thus the need for new models, methods, and software tools able to represent the complete transportation system, including new active modes and business and organizational models for freight, automated vehicles, etc. The literature on using personal rapid transit [23,40], buses [109], and taxis [43] expands this flexible delivery method. The papers of the Ghilas [33,110–113] team are particularly noteworthy. It would also be a good choice to integrate drones, auto-driving truck, intelligent locker, and household pipeline capsule in the conditional new urban area.

5.1.5. M-ULS Operation Scheme

The research on the operation scheme lacks information on carrying capacity, priority, and speed of single-track trains. To fill the gap, we can learn from the existing research on mixed passenger and freight transportation of traditional "heavy" railways by, firstly, quantifying the impact of freight on passenger transport [114] to excavate the maximum carrying capacity of the existing line network [115] and, secondly, by setting up comprehensive transport trains with different priority levels [116] and speeds [117] based on comprehensively considering cost-effectiveness, transportation timeliness, and other factors [118] to comprehensively optimize the train operation scheme.

5.2. Application Implementation

5.2.1. Policy-Making

Few studies address policy-making processes, and there is a need for tools supporting policymakers in designing sustainable policies appropriate for subway freight and underground space (e.g., the co-design with government, the subway company, and the logistics company). This implies incorporating into simulation and optimization tools a managerial perspective and a representation of the business models of the various stakeholders in terms of contracts, pricing, and costing schemes and operational issues. An appropriate regulatory framework and legal constraints are essential for managing property rights and managing underground use and development.

5.2.2. Planning of Underground Space

With the growth of global population and the acceleration of urbanization, the utilization of underground space has become more and more frequent. The research on network layout only stays in the field of transport planning, ignoring the geological structure, surface and underground space use. However, the fact is that as the underground is increasingly used for different purposes, the alignment of tunnels becomes more and more difficult [26]. The construction of a M-ULS tunnel also needs a comprehensive planning method.

5.2.3. Design of Integrated Dispatching System

The design of an integrated dispatching system, e.g., hyper connected systems (metro system, Physical Internet, synchro modality), is largely viewed as a key concept for the M-ULS. Stakeholder cooperation and the integration, synchronization, and automation of operations are at the core of these concepts and development frameworks. Yet, current studies of such systems are few, and their representations are still quite simplified.

5.2.4. Facility Transformation

The transformation of metro wagons and stations has stayed at the "form level", planning the freight organization process and facilities layout, while ignoring the research on the "performance level". This means that there is a lack of quantitative analysis related to civil engineering, structural mechanics, and mechanical design. The references of UCTS [45,98,99] provide some enlightenment as to the station construction. Japanese Super Rail Cargo [119], European NGT CARGO [120], and German CargoMover [121] can also provide some design references for integrated transport vehicles.

5.2.5. Operational Safety

Safe operation and emergency management are other important restrictive factors. We cannot ignore the safety problems caused by mixed passenger and freight transport, as well as the threats to personnel and goods caused by subway derailment and other operation accidents, floods, earthquakes, terrorist attacks, and so on. Efficient and rapid emergency evacuation organization is also an urgent problem to be solved. At the same time, the environmental externalities brought by the metro also cannot be ignored, such as the vibration [122].

6. Conclusions

The research in the field of underground logistics and public freight transportation shows a trend of rapid growth. Many research articles appear in journals with high IF, such as Tunneling and Underground Space Technology and Transportation Research Part B/E, or in professional academic conference organizations such as ISUFT, ASCE, ACUUS, and are produced by research teams such as Qihu Qian, Ghilas, and Siamak Ardekani. However, international cooperation is not strong, and a positive and powerful global cooperation atmosphere has not yet been formed. Through the time zone distribution of keyword contribution and data mining clustering, we draw the evolution path map of the literature, obtain 17 categories with time axis characteristics, detect 20 salient words, and construct a knowledge taxonomy to structure the recent relevant literature. Based on the scientometrics results, we summarize a series of topics in the field of ULS and public freight transport, including the concept and significance of ULS, urban planning scheme, transport vehicle, rail transit coordinated transport mode, and network operation research. Finally, we summarize the shortcomings and gaps of M-ULS, and highlight the enlightening parts of the existing ULS and public freight research on M-ULS.

Due to the lack of mature projects, public and private interests, and investment costs, there is a lack of quantitative economy and applied research, which also leads to the lack of international and inter group cooperation. Future research should gradually tend to the application of systematic implementation and construction. The primary problem is to clarify the project construction investment and construction subject. The government should be an ideal choice to promote the formation of a mature system. In addition, concerning applied research, large-scale simulation, policy-making, underground space utilization, mechanical structure design, integrated dispatching system, and safe operation guarantee are also hot issues to be studied.

The novelty of this study lies in two aspects. On the one hand, the scientific cartography method is incorporated into the systematic literature review process. The scientific mapping method consists of data mining and content analysis, which can minimize subjective randomness, master useful information, and facilitate in-depth thematic analysis. On the other hand, this study focuses on M-ULS and integrates the enlightenment of ULS and public transport related literature on the development of M-ULS, which will help to find research gaps and emerging knowledge branches regarding M-ULS, and further promote the improvement, practice, and innovation of existing research.

Inevitably, this study also has some limitations. Firstly, the search field was limited to the "Title" to avoid invalid records. This retrieval strategy undoubtedly leads to the loss of some literature related to the topic. Secondly, considering the applicability of CiteSpace, although we modified and converted the data format, it also caused some data to be missing. These limitations may affect the statistical results, but have little effect on the concentration of research trends and topics discussion.

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