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Research Progress and Hot Frontier Analysis of Container Terminal Transportation Operations

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Abstract: Using CiteSpace software and bibliometric method, 652 articles related to container terminal transportation operations in WOS core collection database were visualized and analyzed. Based on the network knowledge graph of document distribution of time and space, core author, research institution and key words, this paper analyzes the overall distribution, research hotspot, evolution context and frontier trend of container terminal transport operations research, in order to enrich the perspective of container terminal transport operations review study, and provide reference for promoting the construction of container terminals in our country.

Keywords: Transportation Operations; CiteSpace; Research Hotpots; Trends.

1. Introduction

The development and application of Internet technology and artificial intelligence technology, as well as the emergence of the concept of smart port, have promoted the great development of container terminal construction, and the transportation operations of container terminals have also attracted extensive attention from scholars [1]. The container terminal can be divided into five main areas, namely, berths, wharves, transportation areas, storage yards and gates. The berths and quays areas are considered waterfront, while the yard and gate areas are considered inland. The shipping operations of a container terminal connect seaside, yard and land-based processes [2].

Domestic and foreign scholars have carried out a large number of theoretical studies on container terminal transportation operations and accumulated rich experience in practical exploration, such as (Haralambides [3][4]; Olivier and Slack [4][5]; Dekker and Verhaeghe [5] [6]; Liu and Medda [6] [7]) studied the port operating system on the direction of port infrastructure construction and future strategic expansion. [6] However, from the perspective of literature metrology, there is a lack of systematic sorting out of the hot spots and development context of the research on container terminal transportation operations in recent years. Therefore, based on the scientific knowledge map, this paper uses the visualization analysis software CiteSpace to conduct data mining and metrological analysis of the research literature on container terminal transportation operations, and finally displays the hot spots, knowledge frontiers and academic development of container terminal transportation operations intuitively and clearly by means of information visualization. In order to provide reference and theoretical reference for promoting the construction of container terminals in our country.

2. Data Sources and Methods

2.1. Data Sources

The Web of Science Core Collection database contains more than 12,000 of the world's leading and high-impact academic journals, dating back to 1900 [7]. This paper uses this as the data source for literature retrieval, adopts the method of subject retrieval, selects the Web of Science core collection database, and carries out subject retrieval by "Container terminal transport operations". The retrieval time limit is from the establishment of the database to May 16, 2025. A total of 804 literature records were obtained, and 197 literature records were excluded from editorials, conference abstracts, letters and other articles unrelated to the topic, and finally 625 literature records were included.

2.2. Analytical Methods

CiteSpace6.3. R3 software was used for bibliometric analysis. The literature records retrieved by Web of Science were exported in plain text format, named "download_.txt", and imported into CiteSpace6.1. R3 software for data conversion. Parameters of the graph node were set as follows: time partition was set to January 1998 - May 2024, time slice was set to "1"; The threshold value was set to Top50, and the node types were set to author, institution, country, keyword and other types respectively, which were drawn into corresponding graphs to realize the visual analysis of shipping operations in container terminals.

3. Literature Feature Analysis

3.1. Trend of Publication Volume in the Past Year

The number of published papers in a research field is an important indicator to measure the research activity of the field in a specific time period. The annual distribution map of 625valid journal articles selected in this paper can directly reflect the research development trend of this field in this period of time.

As shown in Fig. 1., during 1998-2024, the number of published literatures related to container terminal transportation operations showed an overall trend of fluctuation and increase. From 1998 to 2011, this field was in its initial stage, with a slow annual growth in the number of publications, and the first peak occurred in 2011. After 2011 to 2019, this field experienced a period of rapid development, among which the number of publications reached the highest in 2019, with 45 articles. From 2022 to 2023, the number of published papers in core journals was at a high level, reaching 44; The decrease in 2024 is related to the statistical time of

this paper (the paper is up to the end of May 2024). In general, the research on container terminal transportation operations is relatively complete, but there are still many new subdivisions to be further explored.

Fig 1. 1998-2024 Container Terminal Transportation Operations Publications

3.2. Authors and Research Institutions

Use CiteSpace6.3. R3 software to form a knowledge map of author cooperation network, analyze the cooperation network of literature authors and the cooperation network of institutions for visual analysis, and select "author" and "institution" as the nodes. The results are shown in FIG. 2 and 3, with 437 nodes and 390 connections. The network density is 0.0041. In the figure, the color warmth represents the distance of time, each node represents a single author/institution, the node size represents the number of published papers and academic influence between the research author and the institution, the connection between the nodes represents the cooperation between them, and the thickness of the connection represents the closeness of the cooperation between the authors or institutions [8]. The node connection strength and network density in the graph are close, indicating that research institutions are closely connected and academic cooperation and exchanges are close. The analysis shows that there are 283 research institutions involved in the study of container terminal transportation operations, mainly distributed in universities. In terms of the total amount of literature published, half of the top 10 research institutions is from Chinese universities, indicating that China has obvious advantages in this research field. What should be paid attention to is that the cooperation network of various research institutions is relatively scattered, and the cooperation between domestic and foreign research institutions is not close, and there is still a great room for improvement of cooperation and exchange between research institutions. From the analysis of the authors, this study involved a total of 437 authors and 283 scientific research institutions. According to Price's law, the number of published papers by the core authors should be ≥ 50% of the total number of papers, which is considered to form a core author group in this field. The formula is $M \approx 0.749 \times \sqrt{N_{max}}$, which can be calculated as M = 2.37. It is found in this study that 95 authors with ≥2 published papers are classified as core authors, and the number of published papers by core authors is 266, accounting for 43.75%, indicating that core authors in this research field have formed [9]. The graph shows that multiple research groups have formed in this field, among which the research network graph with He and Junliang as the core author has the largest number of published papers, followed by the research team represented by Kim and KH with 10 and 6 published papers respectively.

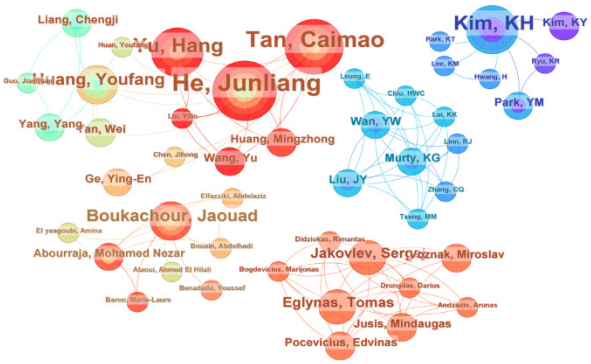

Fig 2. Study authors co-present the map

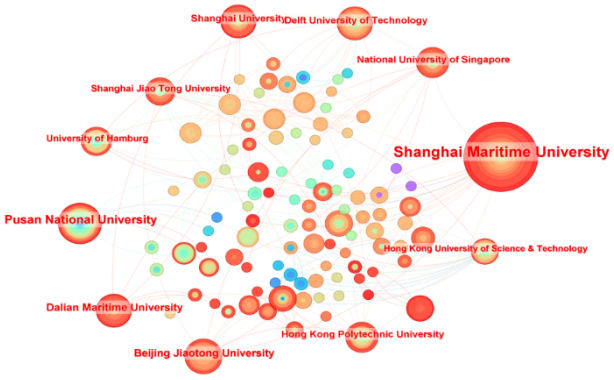

Fig 3. Co-occurrence map of research institutions

Table 1. The top 10 institutions in terms of the number of research publications

serial number	institution	Number of publications (articles)
1	ShanghaiMaritime University	52
2	Pusan National University	22
3	Beijing Jiaotong University	15
4	Dalian Maritime University	15
5	Delft University of Technology	12
6	Shanghai University	12
7	Hong Kong Polytechnic University	11
8	National University of Singapore	11
9	Shanghai Jiao Tong University	10
10	University of Hamburg	10

3.3. Research Countries

The research results show that a total of 63 countries and regions are involved, and the top 3 countries with the number of published papers are China (171), the United States (64) and Germany (33), as shown in FIG. 4. The top 10 countries in terms of publication volume are shown in Table 2. China has the highest number of published documents and its document centrality (0.32), indicating that China has a certain influence in this research field. In Figure 2, the lines between countries represent the cooperative relations between countries, with China maintaining a close cooperative relationship with France, and the United States cooperating closely with Germany, South Korea, Canada and other countries.

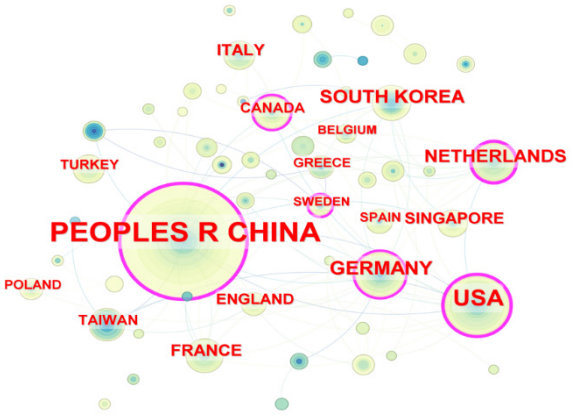

Fig 4. Study of the national co-occurrence map

Table 2. Top 10 countries in terms of research publications

serial number	country	Number of publications (articles)	centrality	First publication time
1	PEOPLES R CHINA	171	0.32	2003
2	USA	64	0.27	2002
3	GERMANY	33	0.19	2002
4	SOUTH KOREA	26	0.08	1999
5	NETHERLANDS	24	0.21	2004
6	FRANCE	17	0.08	1998
7	ITALY	16	0.04	2009
8	SINGAPORE	15	0.02	2003
9	ENGLAND	13	0.07	2005
10	CANADA	12	0.14	2011

3.4. Research Hotspot and Frontier Analysis

3.4.1. Research Hotspot and Frontier Analysis

Keywords are a high generalization of the content of the literature, reflecting the research theme of the literature, and can understand the central idea expressed by the author as a whole. The more times the keywords appear, the larger the nodes appear in the graph, and the larger the font. The keywords "container terminals" and "container terminal" appeared 73 and 66 times, respectively, as the most basic terms in the study. In terms of transportation operations, the focus of attention is "operations", "management", "allocation", "systems", "assignment", etc., and the key words reflecting the research methods in this field are "operations" research ", "model", "algorithm" and "simulation"; See Figure 5. It can be seen that optimization is a hot research topic in this field. The international research on container terminal transportation operations has always maintained a high heat.

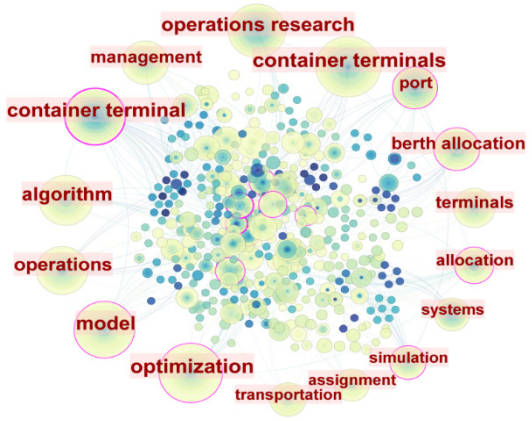

Fig 5. Study of the national co-occurrence map

3.4.2. Keyword Cluster Analysis

CiteSpace software and Log-likelihood Rate (LLR) algorithm were used to form a keyword clustering pattern, in which the research theme was formed based on the hot

network pattern, and the main research fields were directly displayed. As shown in FIG. 6, the first 14 clusters are selected to be presented. The sequence number of clusters is inversely proportional to their scale, and the largest cluster is marked with #0. Module value Q=0.7641, average contour value S=0.9065, Q value greater than 0.3, S value greater than 0.7, the cluster structure is reasonable, efficient and significant, the 14 clusters can be further summarized into the following four aspects.

First, Intelligent container terminal transportation operation, including #0 multi-agent system, #3 automated container terminals and #4 artificial intelligence, #13 automated guided vehicle. Many scholars have carried out research on how to promote the intelligent development of container terminal transportation operations from the perspectives of multi-intelligence system, artificial intelligence and automated guided vehicle. Yu Zhang etal. [10] regarded the terminal operating system as a multi-agent system and proposed a dynamic cooperative speed regulation strategy of multi-carrier robots oriented to swarm intelligence, so as to realize intelligent and distributed traffic control of container terminals. Pourmohammad-Zia, N etal. [11] proposed a new robust optimization method to evaluate the time and cost effectiveness of applying AGV lineups to container pick-up and delivery problems in Rotterdam Port in the Netherlands and Valparaiso Port in Chile. Zheng Xing, etal. [12] considered the integrated scheduling problem of variable speed AGVs and quantified the value of adjustable speed, providing a new idea for port operators to improve port efficiency and save energy.

Second, transportation operation modeling and simulation, including #1 evolutionary algorithms, #2 stochastic modeling, #6 machine learning and #12 data mining. Yue L etal. [13] proposed a two-stage dual-objective mixed integer programming model, aiming to maximize customer satisfaction, minimize AGV invalidity time and minimize QC delay time. Chen X etal. [14] proposed a port environment path optimization model based on artificial potential field and twin delay depth Deterministic strategy gradient (APF-TD3) framework, which ensured the stationality and security of the path on the basis of optimizing the path. Li N etal. [15], established a novel three-level occupational queuing model to estimate the queuing time of external trucks (as well as internal trucks) in a single or double transaction. Pjevcevic D etal. [16] propose a decision method based on data envelopment Analysis (DEA) to determine efficient container loading and unloading processes in port container terminals (PCTS) (considering the number of automated guided vehicles (AGVs) adopted)

Thirdly, hot issues of transportation operation research, including #5storage allocation, #7transshipment operation, #8 container handling and #9 traveling salesman problem, The port performance evaluation has changed from the traditional operation efficiency evaluation to the environmental efficiency evaluation. DiVaio, etal. [9] used the Balanced Scorecard Model to investigate the green performance level of major Italian ports from the perspective of improving the sustainable development capacity and energy efficiency of ports. Hua, etal. [10] using fuzzy importance performance analysis (Fuzzy Importance Performance Analysis) determine the port of Zhuhai green performance level, and on the basis of environmental governance policies are put forward. Wan, etal. [11] built an evaluation system to quantitatively measure the green development level of the port based on the driver, pressure, State, Impact and Response (DPSIR) framework.

Fourth, green sustainable development, including #10 energy consumption, #11port sustainability, the international academic community has conducted in-depth research on reducing energy consumption and port sustainability issues. Vaishnav, et al. [12] discussed the economic and environmental benefits brought by the adoption of shore power technology in American ports. The study of Sciberras, et al. [13] shows that the use of shore power can effectively improve the air quality of port areas and their hinterland cities. In terms of scientific and technological innovation, Wang, et al. [14] proposed to apply artificial intelligence and blockchain technology to the construction of green ports. Zis, et al. [15] analyzed the role of scrubbers in the treatment of sulfur oxides in ship exhaust. Hervas, et al. [16] aimed to develop a fully automated Terminal Operating system for container terminals to promote the green and low-carbon development of ports.

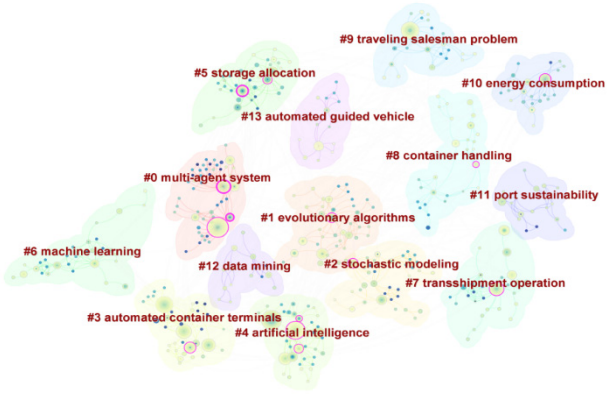

Fig 6. The co-occurrence map of hotspot clustering was studied

3.5. Evolution Analysis of the Research Theme of Container Terminal Transportation Problems

The time zone chart can show the change trend of research keywords over time. Figure 6 shows the time zone graph of research keywords for the transportation problems of container terminals from 1998 to 2024. The numbers above the trend chart indicate the year identifier, while the lines indicate that the keywords co-appear in the same research journal literature. In Figure 6, the time zone map of the research keywords of vehicle routing problems from 1998 to 2024 is subdivided according to the time axis, and the larger the circle is, the more obvious the change trend is. It can be seen that "#1 evolutionary algorithm" and "#9 traveling salesman problem" are the first hot spots to be studied, while "#9 traveling salesman problem" has a larger trend at the beginning and then gradually decreases. And the "#1 evolutionary algorithm" decreased after the trend increased in about 2003. From 2000 to 2005, scholars focused their research on "#1 multi-agent system", "#3 automated container terminal", "#4 artificial intelligence", "#6 machine learning", "#7 transfer operation", "#11 port sustainability" and "#13 automatic guided vehicle". "#2 random modeling", "#5 storage allocation", "#12 control system", "path optimization", "cross entropy" and "dynamic demand" have been paid attention by scholars from 2005-2010 until 2020. The development trend of each keyword in time can be clearly understood by using the time-zone view graph analysis. Help to clarify the development of keywords.

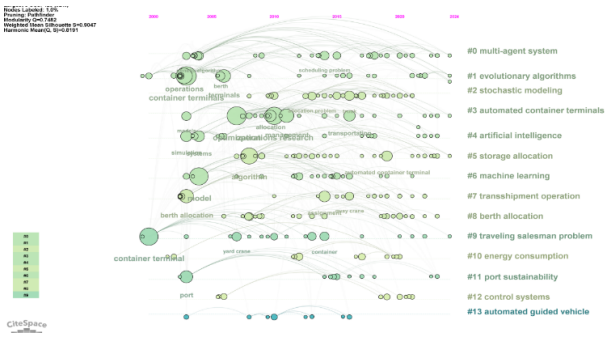

Fig 7. Clustering keyword timeline map

Top 21 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2005 - 2024
container transportation	2005	4.01	2005	2011	
automated guided vehicles	2006	4.82	2006	2015	
space allocation	2008	4.48	2008	2016	
system	2008	3.77	2008	2012	
decision support system	2008	3.62	2008	2015	
operations research	2009	12.05	2010	2015	
transshipment	2011	5.26	2011	2015	
container terminal	2006	4.34	2011	2013	
agvs	2008	3.43	2013	2016	
scheduling problem	2014	4.41	2014	2017	
port	2008	3.99	2014	2019	
systems	2010	3.47	2014	2018	
container terminals	2005	4.84	2016	2018	
network	2016	3.49	2016	2020	
policy	2018	3.24	2018	2019	
truck	2019	4.62	2019	2024	
time	2013	3.2	2019	2020	
storage	2010	3.16	2020	2021	
yard crane	2016	4.08	2021	2024	
automated container terminal	2008	7.14	2023	2024	
integrated scheduling	2008	3.36	2023	2024	

Fig 8. The top 21 highlight the keyword knowledge graph

4. Research Conclusion and Prospects

Based on the visual analysis of the core journal literature on the research of container terminal transportation operations in CNKI database from 1998 to 2024, and combing through the representative literature, the following conclusions are drawn:

(1) From 1998 to 2024, the number of publications related to container terminal transportation operations problems showed a fluctuating upward trend. In general, the research on transportation operations is relatively complete, but scholars prefer independent research, and the cooperative relationship between them is relatively loose and the group size is relatively small. Most of the research institutions are colleges of universities, but the cooperative relationship between research institutions is not close. In the future, China needs to strengthen the construction of the core team for the research of container terminal transportation operations, and continuously improve the quality and quantity of documents issued.

(2)The focus of research on container terminal transportation problems mainly focuses on evolutionary algorithm, storage allocation and traveling agent problem. Among them, route planning methods based on genetic algorithm, simulated annealing algorithm and other optimization algorithms have been widely concerned, which can effectively improve the efficiency and reliability of vehicle route distribution. In addition, intelligent path planning technology is also one of the hot spots of current research, it can automatically adjust the route of vehicles at the dock according to real-time traffic information and user needs, so as to achieve more efficient vehicle transportation. Storage model is an emerging research direction in recent years, which aims to design a more comprehensive, feasible and optimized transportation operation plan by considering storage.

(3)In the study of container terminal transportation operations, the problems related to loading and unloading, transshipment, berthing and control are also paid much attention. By using mathematical models, intelligent algorithms and other methods, researchers explore how to find effective scheduling strategies to improve the efficiency of transportation operations, so as to shorten the transportation operation time and reliability. The research topics in the field of container terminal transport operation problems are closely related to international development, and the research direction is often influenced by the specific transport policies at the time. At the same time, the research content is constantly developing and evolving with time and different research on transport operations problems.

(4)The research field of container terminal transportation operations has undergone evolution in different times, and the hot research trends are constantly changing. In recent years, with the rapid development of emerging technologies, scholars have paid more and more attention to the application of emerging frontier technologies such as big data, automation, artificial intelligence and multi-intelligence systems to the research field of transportation operation problems in order to improve the depth and breadth of research. This also indicates that the future research on container terminal transportation operations will develop in the direction of multi-disciplinary cross-integration, which will promote the further development of container terminal transportation operations research.

Future research should continue to focus on intelligent algorithms, storage allocation and control systems, and further explore how to consider the impact of transshipment, berth allocation and energy consumption on transportation operations. In addition, with the continuous development of container terminals and the continuous application of intelligent technology, it is necessary to pay attention to how to apply artificial intelligence, big data and other technologies to the research of transportation operations, so as to achieve more efficient, intelligent, reliable and sustainable transportation operations. The research of container terminal transportation operations has broad prospects and high application value. The future research can start from the aspects of intelligent path planning, multi-dimensional path planning, intelligent scheduling and environmental protection, so as to continuously improve the efficiency of transportation operations and reduce the cost

References

[1] Use CiteSpace software to form a knowledge map of research institutions' cooperation network. Analyze the distribution of publication institutions to understand Duinkerken M B, Dekker R, Kurstjens S T G L, et al. Comparing transportation systems for inter-terminal transportation at the Masssvlakte container terminals[J]. 2006, 16(2): 469-493.

[2] Carlo H J, Vis I F A, Roodbergen K J. Transport operations in container terminals: Literature overview, trends, research directions and classification scheme[J]. European journal of operational research, 2014, 236(1): 1-13.

[3] Haralambides HE. Competition, excess capacity, and the pricing of port infrastructure[J]. Int J Marit Econ, 2002, Four (4): 323-347.

[4] Olivier D, Slack B. Rethinking the port[J]. Environ Plann A, 2006, 38(8):1409–1427.

[5] Dekker S, Verhaeghe RJ. Development of a strategy for port expansion: an optimal control approach[J]. Marit Econ Logist, 2008, 10(3):258–274.

[6] Liu Q, Medda F. Port infrastructure efficiency: the Europe-Mediterranean case[J]. Int J Shipp Transp Logist, 2009, 1(4): 361–385.

[7] WEI Jianbo, Zhou Jie. Data Entry Principles OF WEB OF SCIENCE and implications for authors [J]. Science and Technology Management Research,2016,36(11):202-204.

[8] Li Jie, Chen Chaomei. CiteSpace: Science and technology text mining and visualization [M]. 3rd edition. Beijing: Capital University of Economics and Business Press, 2022:1.

[9] Research on community membership based on core author research interest similarity Network * -- A case study of information science in China [J]. Books intelligence work, 2018 on conversion (12): 57-64. DOI: 10.13266 / j.i SSN. 0252-3116.2018.12.008.

[10] Zhang Y, Yang C, Tang K, et al. Study on Distributed Consistent Cooperative Control of Multi-ART in Automated Container Terminals[J]. IEEE Access, 2022, 10: 122965-122980.

[11] Pourmohammad-Zia N, Schulte F, Gonzalez-Ramirez R G, et al. A robust optimization approach for platooning of automated ground vehicles in port hinterland corridors[J]. Computers & Industrial Engineering, 2023, 177: 109046.

[12] Xing Z, Liu H, Wang T, et al. Integrated automated guided vehicle dispatching and equipment scheduling with speed optimization[J]. Transportation Research Part E: Logistics and Transportation Review, 2023, 169: 102993.

[13] Yue L, Fan H, Ma M. Optimizing configuration and scheduling of double 40 ft dual-trolley quay cranes and AGVs for improving container terminal services[J]. Journal of Cleaner Production, 2021, 292: 126019.

[14] Chen X, Liu S, Zhao J, et al. Autonomous port management based AGV path planning and optimization via an ensemble reinforcement learning framework[J]. Ocean & Coastal Management, 2024, 251: 107087.

[15] Li N, Haralambides H, Sheng H, et al. A new vocation queuing model to optimize truck appointments and yard handling-equipment use in dual transactions systems of container terminals[J]. Computers & Industrial Engineering, 2022, 169: 108216.

[16] Pjevcevic D, Nikolic M, Vidic N, et al. Data envelopment analysis of AGV fleet sizing at a port container terminal[J]. International Journal of Production Research, 2017, 55(14): 4021-4034.