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Network analysis and the evolution of key concepts in container terminal research

U.G. Samatov¹ ^a

¹Tashkent State Transport University, Tashkent, Uzbekistan

Abstract:

In the contemporary global economy, characterized by increasing supply chain complexity, container terminals (CTs) play an indispensable role in ensuring the efficiency of international trade. This study aims to conduct a network analysis to identify the evolution of key concepts within the field of CT research. The primary objective of the article is to identify dominant thematic clusters and current research directions using scientometric tools, particularly VOSviewer software and data from Scopus and Web of Science databases. Furthermore, an important task is to assess the applicability of the identified global trends for the development of the transport and logistics system of the Republic of Uzbekistan. The findings demonstrate the multidimensional nature of CT research, highlighting both established clusters (operational efficiency, infrastructure design, supply chain integration) and dynamically developing areas, primarily related to digitalization and sustainability. The analysis also enabled the identification of conceptual shifts and so-called "hot spots" within this scientific domain. The concluding section discusses the significance of these results for formulating scientifically-grounded approaches to the modernization and development of CTs and transport-logistics centers in Uzbekistan, aligning with national strategic priorities, and for determining promising vectors for future research.

Keywords:

Container terminal, network analysis, scientometrics, keyword analysis, evolution of concepts, logistics, supply chain management, transport infrastructure, VOSviewer, Uzbekistan

1. Introduction

The effective functioning of container terminals (CTs) is a key factor in ensuring the continuity and economic feasibility of international trade, especially given its steady growth and the increasing share of goods transported in containers [13, 16].

In this context, a deep understanding of the current state and future development prospects of research dedicated to CTs becomes particularly relevant. Analyzing the terminology and key concepts in this field will not only help systematize the accumulated knowledge but also identify the most significant research frontiers and promising areas for further study, thereby contributing to the standardization of approaches and improving professional communication.

Optimization of terminal operations directly affects the reduction of time and cost expenditures in logistics chains [15, 16], which is one of the key factors for the competitiveness of national economies. Studying the evolution of key concepts related to CTs—from their initial perception as simple transshipment points [7] to modern understandings of them as complex logistics hubs offering a wide range of services [8]—is important for both the development of the academic discipline and the practical application of research results.

For the Republic of Uzbekistan, which has no direct access to the sea, the development of an effective transport and logistics system is a strategic priority aimed at overcoming geographic limitations and fully realizing the country's transit potential [5]. State policy in this area is clearly reflected in a number of key legal and strategic documents. For instance, the Law of the Republic of Uzbekistan "On Transport" (No. ZRU-706 dated 09.08.2021) defines the legal basis for transport activities and introduces important concepts such as "transport logistics" and "transport and logistics center" (TLC) [2].

Building on these provisions, the Presidential Decree of the Republic of Uzbekistan "On Measures for the Further Development of the Transport and Logistics System of the Republic of Uzbekistan" (No. PP-28 dated 27.01.2025) outlines the approval of a Development Concept for the transport and logistics system up to 2030 and defines specific goals, including increasing the share of container transportation, creating a network of TLCs, improving the country's ranking in the Logistics Performance Index (LPI), developing international transport corridors, and modernizing infrastructure [3].

These documents testify to Uzbekistan's targeted efforts to transform the country into an efficient transit and logistics hub. The development of modern TLCs and the increase in container transportation are seen as important tools for achieving macroeconomic goals [3, 5], which are particularly relevant for a landlocked country striving to reduce transport costs [2, 6, 14]. Despite the abundance of research on CTs, there is a lack of studies that systematically analyze the evolution of key concepts in this field using quantitative scientometric methods, especially in the context of the needs of developing countries like Uzbekistan. Understanding global scientific trends in CT management, such as port-centric logistics [8] or intermodal connectivity [12, 13], may help Uzbekistan choose the most effective and proven solutions.

Thus, the research problem lies in the need for a systematic analysis of the conceptual structure and development dynamics of scientific knowledge in the field of CTs to identify key trends and adapt them to the conditions of developing logistics systems. The purpose of this article is to conduct a network analysis of key terms in CT research to identify main conceptual clusters and their evolution, as well as to assess the prospects for applying this knowledge to the development of Uzbekistan's transport and logistics system.

^a <https://orcid.org/0009-0006-4323-9048>



A comprehensive understanding of the current state of CT research requires examining the evolution of fundamental concepts, key areas of modern inquiry, and methodological approaches. Historically, the evolution of port system and CT concepts has gone through several stages reflected in theoretical models by foreign scholars. The classical model is considered to be the “Anyport” model by J. Bird (1971) [7], which describes the evolution of port infrastructure. A revolutionary factor was containerization, which led to the emergence of specialized CTs. In response, the concept of “port regionalization” by E. Notteboom and J.-P. Rodrigue (2005) [13] was developed, reflecting the trend of forming extended port systems that include both seaports and inland logistics centers, known as “dry ports” [6, 13, 14]. Modern research, including the works of E. Notteboom, J.-P. Rodrigue, J. Monios, and G. Wilmsmeier [12, 13], emphasizes forms of cooperation and the strengthening of port-hinterland linkages.

Contemporary scientific studies cover a wide range of issues, starting from terminal design and planning (configuration optimization, equipment selection), with the foundational work being the *Handbook on Terminal Planning* by J.W. Böse [8]. A closely related field is operational management and process optimization at CTs, where significant contributions were made by D. Steenken, S. Voß, and R. Stahlbock [15, 16]. Issues of efficiency and productivity, as well as integration of CTs into broader logistics networks (e.g., the concept of port-centric logistics [8]), also remain central. In recent years, there has been growing importance of research on technological innovations [1], automation [11], and the environmental aspects of terminal operations [9, 10].

To study the structure and dynamics of various fields of knowledge, including logistics and transport, scientometric methods such as bibliometric analysis and keyword co-occurrence analysis are increasingly used [10]. Keyword co-occurrence analysis makes it possible to map the conceptual structure of a scientific field. For these purposes, specialized software tools such as VOSviewer [17] are used.

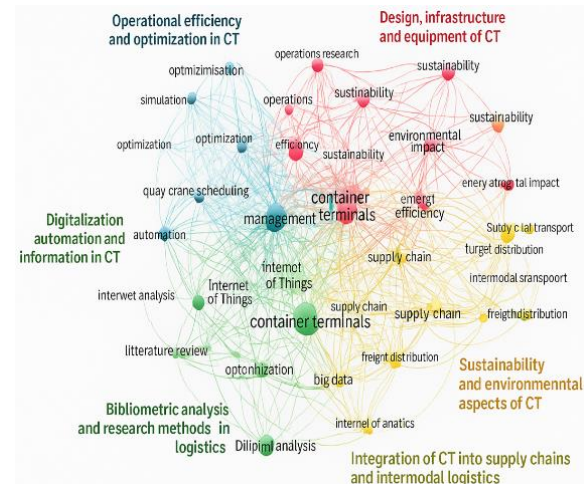
The works of Uzbek scholars, such as Kh. Rakhmankulov, G.R. Ibragimov [4], D.Yu. Khuzhamkulov [5], and others, are mainly focused on analyzing the current state [4], identifying problems [1], and developing proposals for the development of the country's transport and logistics system [5]. Their research often highlights issues such as the underdeveloped infrastructure [4], high transport costs, shortage of qualified personnel [5], and the need for systematic implementation of network and information technologies [1]. This focus on applied tasks creates a favorable basis for applying the results of global conceptual analysis to local conditions.

2. Research methodology

The final dataset, after selection and data cleaning, consisted of 1,258 publications for the period from 2000 to 2025. An increase in publication activity on the topic of container terminals (CT) is observed, especially over the past 5–7 years. Among the most productive journals are *Maritime Policy & Management*, *Transportation Research Part E: Logistics and Transportation Review*, and *Scientometrics*. Geographically, CT research is most actively conducted in China, the USA, the United Kingdom,

the Netherlands, and South Korea. Leading institutions include Delft University of Technology and Erasmus University Rotterdam.

Using the VOSviewer software, a semantic network map of key terms was constructed (Figure 1). This network consists of 88 nodes (keywords that passed the occurrence threshold) and 450 connections between them. The size of the nodes on the map is proportional to the frequency of occurrence of the corresponding keywords, and the thickness of the connecting lines (edges) reflects the strength of their co-occurrence. The VOSviewer algorithm identified six main thematic clusters, marked on the map in different colors.



Picture 1. Semantic network map of key terms in container terminal research (2000–2025). Visualization based on analysis using VOSviewer

The analysis of the constructed semantic network made it possible to identify and characterize six main thematic clusters reflecting the key research directions in the field of container terminals (Table 1).

Table 1
Main thematic clusters and key terms in container terminal research

Cluster name (interpretation)	Main key terms	Brief description/interpretation of the cluster
Operational efficiency and optimization at container terminals	container terminal, operations research, simulation, optimization, efficiency, quay crane scheduling, yard management, berth allocation, stochastic models	The central cluster dedicated to improving the productivity and efficiency of container terminals using mathematical modeling and optimization methods.
Design, infrastructure, and equipment of container terminals	terminal design, layout, port infrastructure, handling equipment, automated guided vehicles (AGV), capacity planning, investment, dry port	Studies of the physical layout of terminals, equipment selection, capacity planning, investments, and the role of dry ports.



Integration of container terminals into supply chains and intermodal logistics	supply chain management, logistics, intermodal transport, hinterland connectivity, port-centric logistics, freight distribution, transport network, resilience	The role of container terminals as nodes in logistics systems, intermodal transportation, connections with hinterlands, development of the port-centric logistics concept, and supply chain resilience.
Sustainable development and environmental aspects of container terminals	sustainability, green port, emissions, environmental impact, energy efficiency, corporate social responsibility (CSR), climate change, circular economy	Reducing the negative environmental impact of container terminals, improving energy efficiency, implementing "green" technologies, and complying with environmental regulations.
Digitalization, automation, and information technologies in container terminals	automation, digitalization, information technology (IT), Internet of Things (IoT), big data, artificial intelligence (AI), blockchain, TOS, smart port	Implementation of advanced digital technologies for automation, improved data management, increased transparency and operational efficiency, and the development of the "smart port" concept.
Scientometric analysis and research methods in logistics	bibliometric analysis, VOSviewer, scientometrics, co-word analysis, literature review, research trends, network analysis	Methodological cluster reflecting the application of quantitative methods for analyzing scientific literature in logistics and container terminals, identifying trends and knowledge structure.

The cluster "Operational Efficiency and Optimization at Container Terminals" stands out due to its size and central position, indicating its maturity and fundamental importance. Clusters related to "Integration of Container Terminals into Supply Chains" and "Design and Infrastructure" also occupy significant places. Relatively new but rapidly growing areas such as "Digitization and Automation" and "Sustainable Development" form distinct clusters, pointing to their increasing relevance.

Overlay visualization by publication years in VOSviewer allows tracking the development dynamics of concepts. Terms related to traditional optimization and design methods were more characteristic of the earlier period studied. Meanwhile, terms related to "automation," "Internet of Things (IoT)," "big data," "sustainability," "green port," and "blockchain" show significant growth in frequency in recent publications, confirming a shift in research focus.

3. Discussion

The network analysis results not only characterize the current structure of this scientific field but also allow

comparison with existing theories and identification of key development directions. The dominance of the "Operational Efficiency and Optimization" cluster confirms the ongoing relevance of productivity improvement challenges. The clusters "Design, Infrastructure, and Equipment" and "Integration of Container Terminals into Supply Chains" emphasize the importance of a systemic approach, consistent with evolutionary port system models such as "port regionalization," and highlight the significance of "dry ports." The emergence and growth of the "Sustainable Development" and "Digitization and Automation" clusters indicate substantial shifts in the research agenda under the influence of global environmental challenges and the potential of "Logistics 4.0" technologies. The cluster "Scientometric Analysis and Research Methods in Logistics" reflects the maturity of applying these methods to understand the field's development.

Identified global research trends have practical significance for the Republic of Uzbekistan, which is actively modernizing its transport and logistics system:

1. Trends in operational efficiency improvement, development of intermodal transportation, implementation of information technologies, and enhancement of connectivity with domestic production centers directly correlate with objectives set by the Law "On Transport," Presidential Decree PP-28, and other strategic documents of Uzbekistan. These include goals such as increasing the share of container transportation and creating a network of modern logistics centers [3, 5].

2. Given its geographic position, Uzbekistan critically needs research and practical solutions in the efficiency of "dry ports" [6, 14], optimization of intermodal logistics chains, and development of transit transport corridors.

3. Comparing the global concept map with the current state of research and practices in Uzbekistan may help identify underexplored but important topics, for example, applying artificial intelligence in predictive freight flow analysis or implementing circular economy principles. Plans for building new logistics centers should consider modern environmental standards and "green" technologies [9].

4. The conducted network analysis can serve as a tool for a more reasoned approach to prioritizing infrastructure investment, developing educational programs for logistics personnel training, and forming a national research agenda.

Several limitations of this study should be acknowledged. First, its results depend on the completeness and representativeness of the selected scientometric databases. Second, the interpretation of thematic clusters and individual terms inevitably contains an element of researcher subjectivity. Third, despite its broad capabilities, the VOSviewer software has limitations for some types of analysis, such as in-depth temporal dynamics analysis. Finally, the main focus on English-language scientific literature may not fully reflect the contributions of researchers publishing in other languages.

Further research in this area may include: conducting deeper qualitative content analysis of publications within each thematic cluster for detailed understanding of discussed issues; constructing and comparatively analyzing conceptual maps for different world regions or types of terminals (dry, river); supplementing co-occurrence analysis with citation and co-authorship analysis to identify the most influential works and researchers; as well as performing a similar scientometric analysis for Russian- and Uzbek-language scientific literature on container terminals and logistics to



identify national specifics and compare them with global trends.

4. Conclusion

The present study, based on the network analysis of key terms, allowed the identification of the multifaceted structure of the scientific field dedicated to container terminals and the characterization of its main conceptual clusters. Both established, fundamental research directions such as operational efficiency and infrastructure design, as well as actively developing emergent topics related to digitization, automation, and sustainable development, were identified. The analysis demonstrated that container terminal research is becoming increasingly systematic, viewing terminals not as isolated objects but as key integrated components of global and regional supply chains.

The scientific contribution of this work lies in the application of objective scientometric methods to systematize knowledge and understand the intellectual structure and evolution of research in the field of container terminals, complementing traditional qualitative literature reviews. The practical significance of the study is especially high for the Republic of Uzbekistan. The identified global trends and dominant concepts can serve as a scientifically grounded guide for informing national transport and logistics policies, strategic planning for the development of container terminals and transport-logistics centers, as well as for determining priority research directions and improving the training system for specialists. Taking into account advanced global experience and current research will enable Uzbekistan to more effectively address the challenges of modernizing transport infrastructure, increasing its competitiveness, and fully integrating into international transport corridors.

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Information about the author

**Samatov
Ulugbek
Gafforovich** Tashkent State Transport
University, Independent researcher
at the Department of "Transport
Logistics"
E-mail: s.ulugbek77@mail.ru
Tel.: +998909470704
<https://orcid.org/0009-0006-4323-9048>



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