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The Hot Spots and Frontiers of Research on Canal Transportation – A Bibliometric Analysis in CiteSpace

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ABSTRACT
As artificial waterway transportation systems, canals played a crucial role in the initial stages of the Industrial Revolution, facilitating faster, more convenient and economically viable mass transportation of goods, thus becoming indispensable components in certain regions' urbanisation and industrialisation processes. This study employs the bibliometric analysis tool CiteSpace to investigate 212 papers on canal transportation from the Web of Science over the past three decades. The objective of this research is to elucidate the knowledge structure through visual representations of collaboration networks, co-citation networks, keyword co-occurrence and clustering patterns. In the findings, we establish author, institution and country co-authorship networks to ascertain the distribution of core journals by determining journal co-citation networks. The literature co-citation network reveals the main research themes and knowledge structure of canal transportation. Influential authors are identified through author co-citation networks, while research hotspots and frontiers are discovered through keyword co-occurrence networks. This study offers a comprehensive and informative perspective on current trends and research developments in canal transportation. Additionally, we propose future research directions with potential prospects to propel the advancement of this field further comprehensively.

KEYWORDS
canal; artificial waterways; waterway transportation; transportation; bibliometric analysis.

1. INTRODUCTION

The earliest form of transportation, canals, guaranteed traffic flow in periods when land transportation was not as convenient [1]. The public considers canals to be conveyance-oriented alterations to rivers [2]. Canals serve as vital artificial waterways with significant implications in various domains, including navigation, agricultural irrigation, hydroelectric power generation, flood control, land drainage, defence and water supply [3]. They have supported economic growth and the movement of people and goods by acting as the leading artificial transport tools for large-scale goods transportation [4–6]. During the initial phases of the Industrial Revolution, the implementation of canal systems brought about a significant transformation in conventional water transportation, emerging as a highly advantageous mode of transportation [7, 8]. The significance of canals extends beyond the mere connectivity of inland waterways. They promote trade development and facilitate economic and cultural exchange among different regions and countries.

Worldwide, five continents' canal systems provide essential links for transportation [9]. Asia is home to the Grand Canal of China, which is the world's longest and largest man-made canal. Its construction dates to 486 BC, and it stretches across 1794 kilometres. This canal has facilitated political, economic and cultural interactions between China's northern and southern parts [10]. The Erie Canal, spanning approximately 584 kilometres, is a crucial link between the five Great Lakes and New York City through the Hudson River in the Americas. This significant waterway has played a pivotal role in facilitating economic growth and population

migration in the Midwest region and serving as a vital trade route connecting the eastern and western areas of the United States. Furthermore, the Panama Canal, with a length of 82 kilometres, plays a pivotal role in facilitating global trade and maritime transportation by connecting the Pacific and Atlantic Oceans. The Suez Canal, a prominent African waterway, spans approximately 194 kilometres and is a crucial link between the Mediterranean and Red Seas. Its strategic location has led to a notable reduction in travel distances and has significantly impacted global trade and shipping [11]. In Europe, numerous cities in different countries depend on canal resources for their development. Examples include the Manchester Canal in the United Kingdom, which spans 58 kilometres and connects Manchester to the Irish Sea, and the renowned Amsterdam Canal Belt and Italy's Venice Canals. These canals connect regions across various directions, including north-south, east-west and even between Europe, Asia and other global locations [12]. Oceania exhibits a notable disparity in the presence of canal systems for transportation when compared to different continents, primarily attributable to its geographical limitations [13]. Most constructed canals are mainly employed for irrigation or flood control, while only a few are designed to facilitate navigation. In general, canals promote global traffic connectivity as an essential part of waterborne transportation networks. They do this by connecting rivers, lakes and other bodies of water, making it easier to link resources across continents and promoting trade, cultural exchange and information, especially before the development of air transportation.

Nevertheless, the emergence of more efficient modes of ground transportation, such as railways and motorised roadways, has brought about substantial transformations in the function of canal transportation. Currently, the primary emphasis of inland waterway transportation lies in the shipment of goods, particularly in handling bulk commodities that exhibit limited price sensitivity and yield substantial profits. According to Bölükbaşı, Balas and Beril, there has been a noticeable upward trajectory in the demand for hazardous chemicals [14]. Additionally, Taylor, Morris and Brown have observed a consistent growth in the demand for goods characterised by their substantial size, weight or unwieldiness [15]. Furthermore, passenger transport is in the form of tourism, including short-haul travel and transit [16, 17]. This encompasses the movement of individuals via ferries and the associated commercial activities at ports [18]. However, it is indisputable that canals function effectively within the transportation system. These entities possess substantial importance and pertinence regarding economic, environmental and social sustainability. Recent developments, such as the Panama Canal expansion completed in 2016 and plans for the Kara Canal in Thailand, demonstrate this point. Canals provide a low-carbon, sustainable mode of transportation that is becoming increasingly popular as concerns about climate change and human living environments grow.

Considering this context, this paper aims to conduct a comprehensive examination and analysis of scholarly works about canal transportation, utilising a combination of qualitative and quantitative research methods. This study will use bibliometric analysis to summarise prevailing research topics and identify the research frontier. Specifically, techniques such as literature co-citation networks, co-cited analysis and keyword co-occurrence networks will be utilised for this purpose. This study will centre its literature review around three key questions.

— Research question 1: What are the temporal, country, structural and disciplinary characteristics of studies about canal transportation?
— Research question 2: What are the prevailing subjects of interest in the field of canal transportation research at present?
— Research question 3: What are canal transportation research prevailing patterns and prospective trajectories?

2. DATA EXTRACTION AND RESEARCH METHODOLOGY

The Web of Science (WoS) is widely recognised as a highly authoritative tool for retrieving scientific literature, providing essential information for important research in the technical domain [19]. The data for this study were retrieved from the Web of Science database, specifically the "Science Citation Index Expanded" (SCIE) and the "Social Sciences Citation Index" (SSCI), created by Clarivate Analytics (USA) in 1997. Canals, as artificial waterway systems, encompass artificial canals and ditches [20, 21].

2.1 Data extraction

Therefore, we defined the research topic as: (TS= canal transportation OR artificial waterway transportation OR artificial inland waterway transportation OR ditch transportation OR aqueducts transportation), indicating the collection of published articles containing these terms in their titles, abstracts or keywords. Initially, 809 articles were screened. It is noteworthy that the term "canal transportation" coincides with a professional term

in dental medicine. Thus, we filtered out dental and medically related papers by excluding them through the "document type" and "citation topic" fields, restricting the language to English, resulting in 212 articles. Subsequently, the retrieved articles were saved as plain text files, comprising complete records and reference citations. They were then converted into an executable format for visualisation using the "Data/ Import/Export" feature of CiteSpace.

2.2 Research methodology

The bibliometric software utilised in this study was CiteSpace (version 6.2.R4). CiteSpace is extensively employed for the processing of literature data, offering capabilities such as the visualisation of knowledge maps and the analysis of research hotspots and emerging trends [22]. This software effectively presents various aspects within the domain of canal transportation, including the number of publications, keyword data, research categories and affiliated institutions. This enables a comprehensive examination of the evolution, significant concepts and interconnectedness among associated research entities in this field. This analysis provides support for a comprehensive comprehension and meticulous examination of prevailing research focal points and patterns.

3. RESULTS AND DISCUSSION

In this section, the software tool CiteSpace is employed to perform visual data analysis on a specific set of 212 articles sourced from the Web of Science (WoS) database. This analysis serves to enhance comprehension of the current state and emerging patterns within the field under investigation.

3.1 Quantitative analysis of publications

The number of publications reflects the development within a particular professional field. Analysis reveals that the earliest literature on canal transportation in the screened texts dates to 1995. *Figure 1* illustrates the distribution of publications on canal transportation over time, from 1994 to 2023. It is observed that from 1995 to 2008, the number of publications remained relatively stable, fluctuating mostly between 1 and 3 articles per year. However, since 2008, there has been a gradual increase in publications, especially during the period from 2010 to 2013. Although there were fluctuations each year, there was an overall significant growth trend. Notably, there was a sharp decline in publications in 2015, with only 2 articles published, but the overall trend continued to rise during this phase. Subsequently, from 2016 onwards, research in the field of canal transportation entered a phase of rapid growth, particularly peaking from 2020 to 2023, reaching 27 articles in 2023. Due to incomplete records for the year 2024 as of the retrieval date, a comparison with previous complete data is not feasible. However, the exponential trend lines in the graph demonstrate sustained academic interest in the topic of canal transportation, with an accelerating growth rate, indicating a forecast of continued gradual increase in academic research and discussion on canal transportation in the future. Overall, over the past 30 years, despite fluctuations, the general trend suggests a continuous and gradual increase in the number of publications on canal transportation, signifying significant progress in the field, particularly in recent decades.

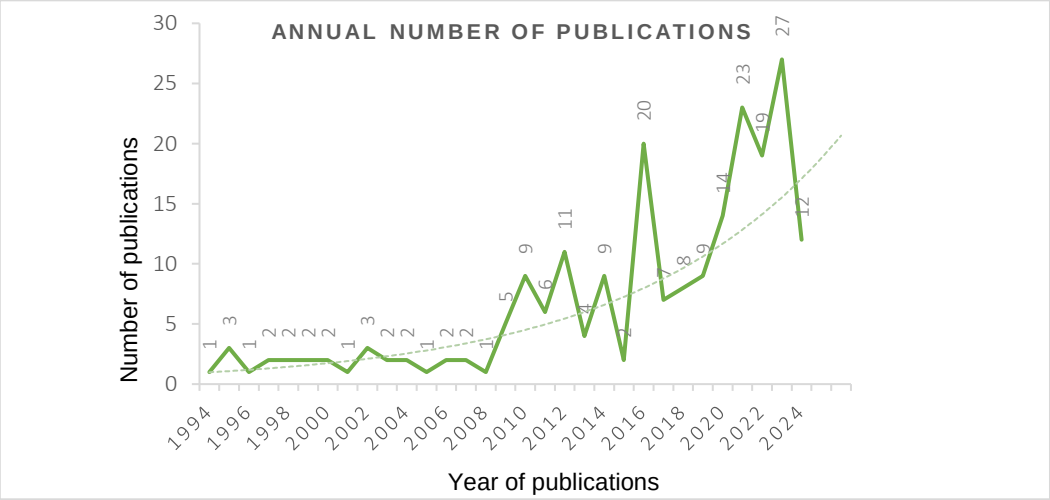

Figure 1 – Trend analysis of the annual number of publications on canal transportation

Table 1 lists the top 10 discipline categories in the field of canal transportation based on the retrieved literature. As articles may belong to multiple categories within the WoS, this could result in the number of publications in the table exceeding the total number of publications. From *Table 1*, Transportation holds the highest proportion, followed by environmental sciences, civil engineering, environmental studies, geosciences, multidisciplinary and transportation science technology, all of which are significant areas in the field of canal transportation. Additionally, the research topic has also attracted the interest of scholars in economics, water resources, geography and green sustainable science technology. This further indicates that over time, the research field has become increasingly interdisciplinary and highly integrated in nature.

Table 1 – Distribution of the top 10 categories in the research on canal transportation

Rank	Number of publications	The percentage of total	Category
1	39	18.40%	Transportation
2	36	16.98%	Environmental sciences
3	27	12.74%	Engineering civil
4	24	11.32%	Environmental studies
5	21	9.91%	Geosciences multidisciplinary
6	21	9.91%	Transportation science technology
7	20	9.43%	Economics
8	18	8.49%	Water resources
9	17	8.02%	Geography
10	16	7.55%	Green sustainable science technology

3.2 Co-authorship analysis

International collaboration is widely acknowledged as a prominent feature of modern scientific production. Researchers transition from independent observers to collaborative team members, gathering complementary abilities and interdisciplinary approaches around common goals, involving collaboration at the individual, institutional and national levels [23]. Utilising social network analysis and collaboration networks as effective means to assess collaboration patterns and identify key scientists and organisations is increasingly prevalent [24]. It aids in understanding the collaboration networks of different authors and discovering productive researchers worldwide in the field of canal transportation from micro, meso and macro perspectives [22].

The first step is the co-authorship analysis. *Figure 2* demonstrates the academic collaboration relationships among authors by selecting the unit of analysis, setting appropriate thresholds and isolating node generation. The size of each node represents the number of articles published by the author, while the distance between nodes and the thickness of links represents the degree of collaboration between authors. Authors are ranked by the number of publications, and the top 10 most prolific scholars out of 267 authors in the 212 articles are listed in *Table 2*. Notably, Lu Jing from Dalian Maritime University, China, has emerged as the most prolific contributor in the field of canal transportation, with a cumulative publication count of 6 articles. Her research primarily focuses on risk assessment of maritime transportation networks, aiming to ensure the safety of straits and canal transportation. For instance, she employs fuzzy evidence reasoning methods to assess the safety and vulnerability of straits or canals in maritime transportation [25, 26]. Additionally, her research addresses related issues such as transportation costs and time efficiency of straits and canals in maritime networks [27, 28]. The scholars ranked 2nd, 3rd and 4th have each published 3 articles related to canal transportation. Yang Zhifeng from Beijing Normal University, China, has simulated and predicted the risks of canal transportation in the South-to-North Water Diversion Project of China [29–31]. Researchers Leitholdt Eva and Zielhofer Christoph from Jena University, Germany, collaborated to discuss the possibility of inland navigation of the medieval early European watershed engineering project, the Karlsgarten Canal, through field surveys and data analysis [32–34]. Scholars ranked 5th to 10th have each published 2 articles. Laska Shirley from the USA, in

collaboration with Freudenburg William R. and Gramling Robert, discussed the negative impacts of excavation projects for transportation canals in the New Orleans area from a sociological perspective on the local economy, politics and environment [35, 36]. Altunkaynak Abdusselam used urban growth models to simulate hydrology and assess risks in the Istanbul area, including discussions on transportation and the Istanbul Canal project [37, 38]. Arts Jos explored the socio-economic value of canal transportation infrastructure [39, 40]. Jiang Meizhi collaborated with the top-ranked scholar Lu Jing on two articles focusing on the vulnerability of straits or canal transportation and the assessment of new risks [25, 26].

This observation indicates that each article associated with these prolific scholars tends to have similarities in research objects, with relatively concentrated and frequent publication times. Moreover, researchers in the field of canal transportation often choose to conduct research in collaboration, which aids in obtaining comprehensive and in-depth research outcomes, thereby enhancing research quality. Furthermore, in the field of canal transportation, scholars' research areas exhibit a trend towards diversification, involving various aspects such as technical, social and economic dimensions, demonstrating the complexity and diversity of research in canal transportation.

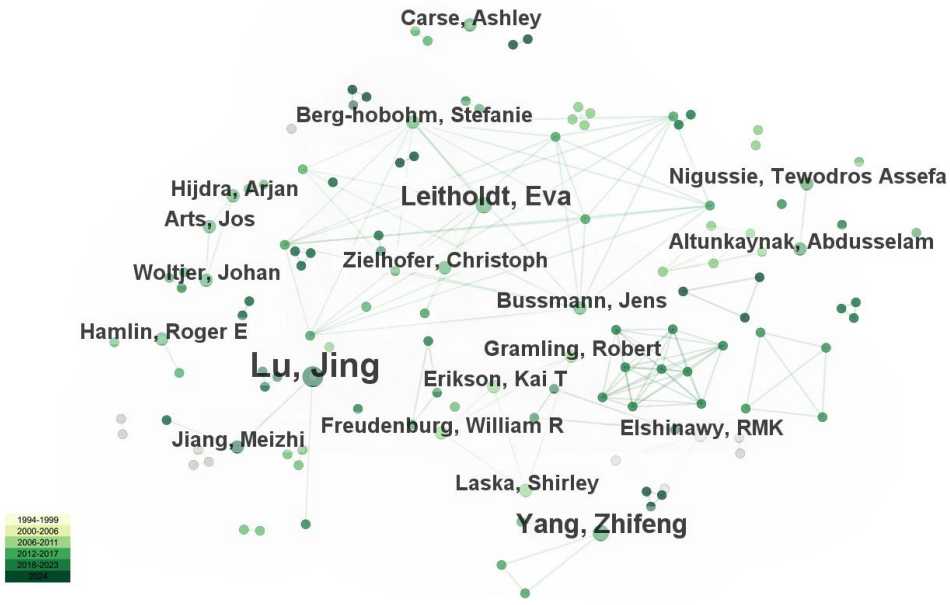

Figure 2 – A visualisation network map of study areas of co-authorship analysis

Table 2 – Top 10 most cited authorship with co-citation frequency on canal transportation

Rank	Frequency	Year	Author
1	5	2019	Lu, Jing
2	3	2014	Yang, Zhifeng
3	3	2012	Leitholdt, Eva
4	3	2014	Zielhofer, Christoph
5	2	2008	Laska, Shirley
6	2	2008	Freudenburg, William R
7	2	2016	Altunkaynak, Abdusselam
8	2	2014	Arts, Jos
9	2	2022	Jiang, Meizhi
10	2	2008	Gramling, Robert

The second is the institutional co-authored analysis. *Figure 3* illustrates the collaboration network established among various institutions in the field of canal transportation. This visualisation encompasses analyses involving countries and co-authorship patterns. The size of each node is directly proportional to its publication count, with a total of 222 institutions participating in this network. According to *Table 3*, which ranks institutions by publication count, Dalian Maritime University and the Chinese Academy of Sciences demonstrated a leading position in publication output in this field, contributing 12 and 11 articles respectively, establishing a noticeable lead over other institutions. Wuhan University of Technology and Shanghai Maritime University rank 3rd and 4th with 5 articles each. It is worth noting that the top four institutions in terms of publication count are all located in China, highlighting China's significant contribution to research in canal transportation.

In subsequent rankings, the Florida State University System in the United States ranks 5th with 4 articles, while Istanbul Technical University in Turkey, Leipzig University in Germany, the Louisiana State University System in the United States, Beijing Normal University in China and Aalborg University in Denmark each contribute 3 articles related to canal transportation and rank 6th to 10th respectively.

It is noteworthy that among the institutions identified in *Figure 3*, only Beijing Normal University in China is not linked with other institutions, indicating weaker academic collaboration with other institutions. Additionally, 50% of the top 10 institutions belong to China, highlighting significant research output from specific Chinese academic institutions in terms of article publications, while institutions from other countries demonstrate less prominent performance.

Figure 3 – A visualisation network map of institution co-authorship analysis

Table 3 – Top 10 most cited institutions with co-citation frequency on canal transportation

Rank	Frequency	Year	Institution
1	12	2019	Dalian Maritime University
2	11	2011	Chinese Academy of Sciences
3	5	2014	Wuhan University of Technology
4	5	2022	Shanghai Maritime University
5	4	1995	State University System of Florida
6	3	2015	Istanbul Technical University
7	3	2012	Leipzig University
8	3	2008	University of Louisiana System
9	3	2014	Beijing Normal University
10	3	2007	Aalborg University

The third step is the country co-author analysis. *Figure 4* illustrates a network analysis depicting the global collaboration patterns and dissemination in the field of canal transportation, comprising 46 nodes and 35 links. In this network, the size of each node represents the number of papers published by that country, reflecting the contribution of each country to research in canal transportation. When a paper is authored by individuals from multiple countries, the paper is assigned to each respective country represented by the authors. This practice is due to the collaborative efforts of multiple authors and institutions from different geographic locations typically represented in research articles [41]. Thus, the analysis of co-author relationships provides insights into the collaboration among authors from different countries and internationally, as well as the contributions of authors from different countries to research efforts. Additionally, it offers valuable insights into the level and consequences of research cooperation between countries and regions.

Based on the data obtained from *Figure 4*, it is evident that the global network of canal transportation research encompasses 46 countries, distributed across different regions. Europe comprises 21 countries, including England, Italy, the Netherlands, Germany and Spain. Asia consists of 16 countries, such as China, Japan, South Korea, India and Singapore. North America includes 3 countries, namely the United States, Canada and Panama. Africa has 2 countries, including South Africa and Egypt, while Oceania has 2 countries, namely Australia and New Zealand. South America's Brazil and Jamaica, along with these, form a relatively concentrated and closely cooperating network, as shown in *Figure 4*.

Table 4 displays the top ten productive countries ranked by publication count. In the field of canal transportation research, China and the United States rank first and second with 65 and 56 published papers respectively, significantly ahead of other countries. Turkey ranks third with 12 papers. England and Germany tie for fourth place with 11 and 12 papers, respectively. The Netherlands ranks sixth with 8 papers. Japan follows with 7 papers. South Korea, Sweden and Norway each rank 8th, 9th and 10th, respectively, with 6 papers each.

It is worth discussing that there are 11 nodes coloured in purple in *Figure 4*, representing England (0.47), South Korea (0.32), Sweden (0.24), Wales (0.23), the Netherlands (0.2), Scotland (0.19), China (0.16), Turkey (0.16), Denmark (0.11), Singapore (0.11) and the USA (0.11). The thickness of connections between purple nodes is proportional to the centrality of countries in the collaboration network. This also indicates that these 11 countries play a crucial role in canal transportation research, especially England.

China and the United States occupy significant positions in the global network of canal transportation research, owing to their extensive canal systems. China boasts one of the world's longest and oldest canal systems, with a history of over 2,500 years [42], providing a solid foundation for research related to canal transportation. Particularly noteworthy is the increasing support and attention from the Chinese government for the Grand Canal since its inclusion in the World Heritage List by the 38th session of the World Heritage Committee in 2014, which has stimulated more scholarly attention to research related to the Grand Canal in China [43]. Similarly, the Erie Canal is the most significant public works project ever built in the United States and the longest canal in the Western world [44, 45]. In 2000, the United States Congress designated the Erie Canalway National Heritage Corridor, acknowledging the significance and impact of this canal system in North America [46]. Additionally, the US government viewed canal and railroad construction as essential measures for directly promoting economic growth, which had a profound impact on the establishment and research of modern transportation systems in the United States [47].

England holds the most important position in the network of canal transportation research, owing to its status as one of the birthplaces of the Industrial Revolution, which was driven by the canal transportation system [48]. England began constructing canals for transportation in the 1760s [49]. The canal network in England not only connected important cities and industrial centres domestically but also played a crucial role in international trade. Due to its historical accumulation and technological prowess in canal transportation, England receives considerable attention in the global network of canal transportation research [50, 51].

The canal resources of these countries provide an important foundation for research in the field of canal transportation, and their positions and influence in the global network of canal transportation research are fully reflected.

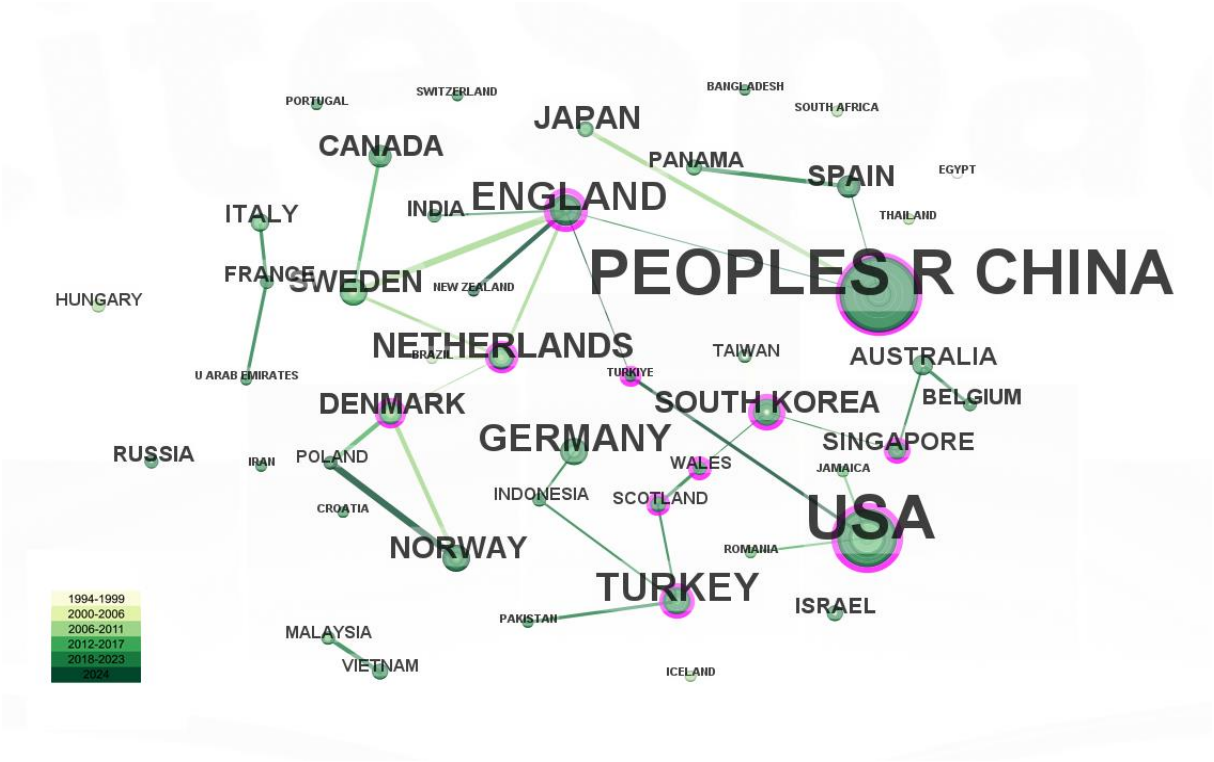

Figure 4 – A visualisation network map of country co-authorship analysis

Table 4 – Top 10 most cited countries with co-citation frequency on canal transportation

Rank	Frequency	Centrality	Year	Country
1	65	0.16	2006	PEOPLES R CHINA
2	56	0.11	1995	USA
3	12	0.16	2010	TURKEY
4	11	0.47	1995	ENGLAND
5	10	0	2005	GERMANY
6	8	0.2	2010	THE NETHERLANDS
7	7	0	1999	JAPAN
8	6	0.32	1999	SOUTH KOREA
9	6	0.24	2002	SWEDEN
10	6	0.05	2007	NORWAY

3.3 Co-citation analysis

Examining co-authorship relationships can serve as evidence of research prowess in the field of canal transportation. However, accurately expressing the contributions of different academic articles and authors in this field can pose considerable challenges [52]. Co-citation analysis refers to the simultaneous citation of multiple journal articles and authors within three articles [53]. In this section, co-citation analysis is employed to identify relationships among journals, literature and authors, and a structural diagram is drawn. The size of nodes is directly related to the number of citations received by the journals, while the thickness of the outer circles surrounding the nodes indicates their centrality. In this section, we will discuss the importance and role

of academic journals in scholarly research. Journals serve as platforms for scholars to exchange research findings. To provide a concise overview of the dissemination of academic journals in canal transportation, the co-citation networks of these journals were visualised using the software tool CiteSpace.

The first step is journal co-citation analysis. Academic journal co-citation analysis is a crucial research method aimed at revealing the overall structure of academic fields and accurately identifying primary research areas [54, 55]. Through this method, we can gain a clear understanding of the interconnections among journals in the academic field. *Figure 5* displays a network structure composed of 133 nodes and 193 edges. The sizes of these nodes reflect the number of co-citations for the corresponding journals, thus illustrating their influence in the academic community. Therefore, the larger the node, the greater the influence of the journal it represents. In *Table 5*, we list the top 10 most influential co-cited journals ranked by the number of co-citations. Additionally, we present the top 10 journals with the highest number of citations, which have high visibility and impact in the academic community. Notably, "Maritime Policy & Management" ranks first with a total of 39 citations, highlighting its importance in the field of canal transportation research. "Transportation Research Part E" and "Journal of Transport Geography" follow closely, each cited 38 times, indicating their significant influence in the field. While their citation counts may not stand out compared to the top three journals, they still reflect their contributions and popularity in specific research areas.

In the top ten ranking of *Table 5*, the journal "SCIENCE" is considered the most important with the highest centrality of 0.51. This is because the journal holds a significant position in a wide range of scientific research fields, with papers that have broad impact and credibility, thus attracting attention in the field of canal transportation research. Following are journals such as "Marine Policy" and "MARIT POLICY MANAG", which serve as important representatives among the co-cited journals, providing researchers with rich academic resources and research outcomes. Through co-citation analysis of journals, we can gain a clear understanding of the distribution of key knowledge sources in the field of canal transportation research. This helps us identify core journals and their relationships, thus better grasping the academic dynamics and development trends in this field. The results indicate that this research field not only covers the discipline of canal transportation itself but also extends to various interdisciplinary areas such as environmental science and economics, highlighting its interdisciplinary research characteristics.

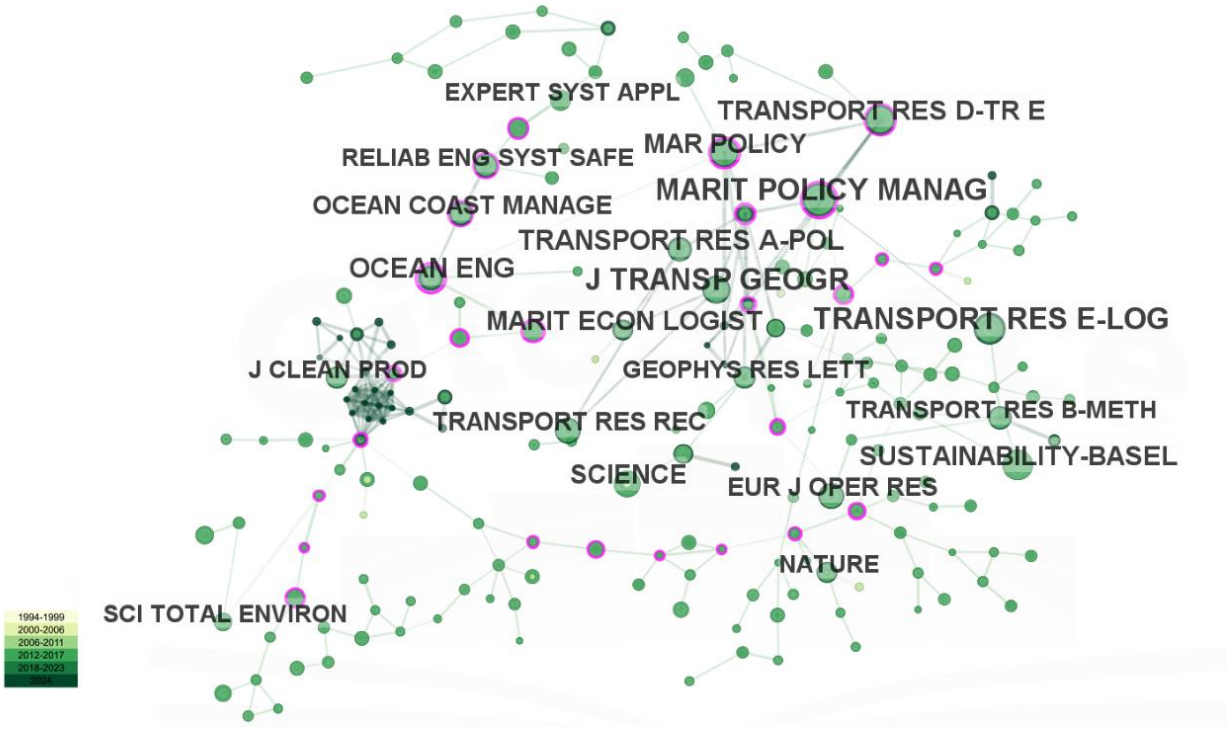

Figure 5 – A visualisation of journal co-citation analysis

Table 5 – Top 10 most co-cited journals

Rank	Frequency	Centrality	Year	Title
1	39	0.31	2014	MARITIME POLICY MANAG
2	38	0.22	2016	Transportation Research Part E : Logistics and Transportation
3	38	0.08	2009	Journal of Transport Geography
4	29	0.29	2016	Ocean Engineering
5	28	0.13	2015	Transportation Research Part A: Policy and Practice
6	28	0.03	2010	Maritime Economics & Logistics
7	25	0	2018	Sustainability-Basel
8	24	0.21	2014	Transportation Research Part D: Transport and Environment
9	23	0.39	2015	Marine Policy
10	22	0.51	2008	Science

The second step is the document co-citation analysis. Citations generated from reference lists are considered an important knowledge base for evaluating the research structure and evolutionary trajectory of canal transportation systems [56]. The document co-citation network in *Figure 6* consists of 215 nodes and 197 connecting edges. Nodes represent documents, and the thickness of the edges indicates the strength of co-citation between documents. The size of the nodes symbolises the importance of the documents, while closely connected nodes indicate documents with higher co-citation frequencies.

Table 6 presents the top ten most frequently cited articles in the research field, ranked by their co-citation frequencies. The top three documents each have six co-citations. Among them, "Feasibility of the Northern Sea Route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker market" by Dimitrios Theocharis stands out. This article explores the feasibility of the Northern Sea Route (NSR) using a speed optimisation model to minimise required freight rates, involving discussions related to the Suez Canal [57]. "Resilience analysis of maritime transportation systems based on importance measures" by Hongyan Dui highlights the importance of resilience management for ports and routes in maritime transportation systems and proposes methods to optimise residual resilience management [58]. "Best maritime transportation option for the Arctic crude oil: A profit decision model" by Olivier Faury develops a profit decision model defining the optimal choices for operating oil producers in the Russian Arctic region, including hybrid routes (Northern Sea Route or Suez Canal route) and ship ice classes (1A, 1AS and Open Water) [59].

Following these, articles ranked 4th to 8th each have five co-citations, covering research on Arctic shipping [60, 61], Panama Canal expansion [62, 63], maritime risk and studies related to transportation cost assessment and decision-making topics [28, 64, 65]. It is worth noting that the top ten co-cited articles predominantly focus on maritime transportation, with relatively fewer co-citations discussing canal transportation in inland shipping. This indicates that research discussing maritime transportation in the context of canal transportation receives more attention. Furthermore, among the top 10 articles, four are from the journal Transportation Research Part E: Logistics and Transportation Review, and three are from the journal Maritime Policy & Management, once again demonstrating the importance of these two journals in the field of canal transportation research.

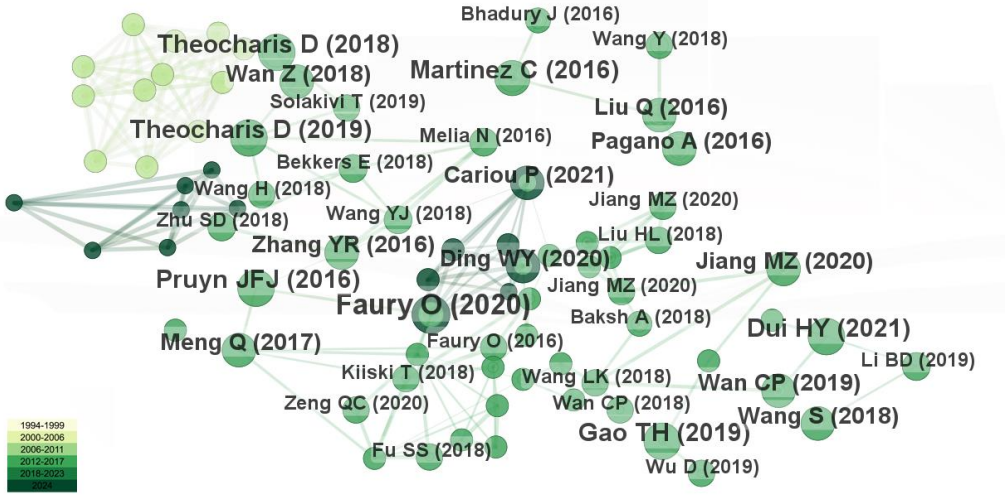

Figure 6 – A visualisation of document co-citation analysis

Table 6 – Top 10 most co-cited documents

Rank	Article	Co-cities	Citation	DOI
1	Theocharis D, 2019	6	75	10.1016/j.tre.2019.07.003
2	Dui HY, 2021	6	119	10.1016/j.ress.2021.107461
3	Faury O, 2020	6	35	10.1016/j.tre.2020.101865
4	Gao TH, 2019	5	27	10.1080/03088839.2019.1594423
5	Theocharis D	5	148	10.1016/j.jtrangeo.2018.04.010
6	Martinez C, 2016	5	34	10.1016/j.tre.2016.04.012
7	Pruyn JFJ, 2016	5	81	10.1016/j.jtrangeo.2018.04.010
8	Wan CP, 2019	5	211	10.1007/s10708-016-9696-0
9	Pagano A, 2016	4	57	10.1080/03088839.2015.1131864
10	Solakivi T, 2019	4	45	10.1016/j.cie.2016.01.007

The third step is the author co-citation analysis. Author co-citation analysis is a crucial method to identify the most important contributors in a research field, often focusing on the first authors of publications [66]. The author co-citation network in *Figure 7* comprises 293 nodes and 703 co-citation edges. Node sizes represent the total co-citations, while *Table 7* presents the top 10 scholars ranked by their co-citation frequencies and the number of times they were cited. Notably, Professor Halvor Schøyen from the Department of Maritime Operations at the University of Southeast Norway has the highest citation count, with 15 co-citations.

Halvor Schøyen primarily focuses on container shipping, particularly engaging in in-depth discussions regarding alternative routes to the Northern Sea Route and the Suez Canal. His research indicates that the Northern Sea Route is approximately 5,380 nautical miles shorter than the Panama Canal route, reducing sailing distances by about 40%. Additionally, the Northern Sea Route can improve vessel energy efficiency by more than double, potentially enhancing supply chain agility and adaptability [67]. Therefore, scholars often cite his research conclusions when discussing canal transportation.

Next, Qiang Meng ranks second with 12 citations. His research spans urban transportation modelling and optimisation, maritime shipping and multimodal freight transport analysis. His critical examination of the feasibility of trans-Arctic routes emphasises the correlation between navigation and commercial characteristics

[68]. However, despite being highly cited, Meng does not possess high centrality in canal transportation research, indicating his relatively lower significance in the field.

Ranked fourth to seventh in *Table 7*, scholars are each cited 11 times. Among them, James J. Corbett extensively analyses the potential impacts of Panama Canal expansion on carbon dioxide emissions and proposes green freight policy measures, emphasising the necessity of considering multimodal network solutions to maximise emission benefits [69]. His research contributions are more prominent in the field of canal transportation compared to other scholars with similar citation counts. Additionally, Dimitrios Theocharis plays a crucial role in canal transportation research. He conducted a comprehensive literature review covering relevant literature from 1980 to 2017 on Arctic routes, traditional routes and canals. His study reveals that existing literature mainly focuses on liner transportation, with secondary attention to bulk cargo transportation. However, he points out that future research should also focus on the potential opening of the Nicaragua Canal and the Kiel Canal, as well as the competitiveness of the Panama Canal and Suez Canal expansions [60].

These scholars, along with others not listed in *Table 7* but still making significant contributions to canal transportation research, have a substantial impact on the development of this field. Their work not only provides theoretical foundations and empirical support but also offers valuable insights for future research directions.

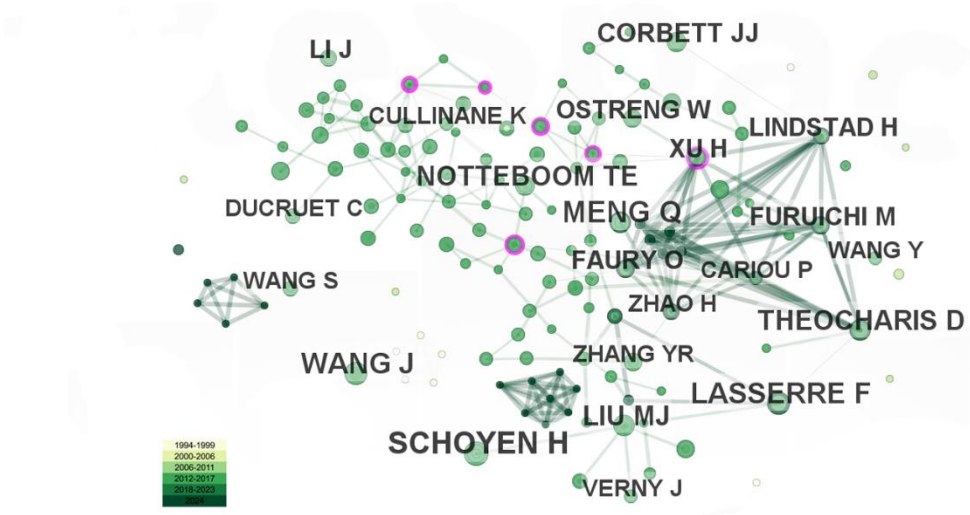

Figure 7 – A visualisation of author co-citation analysis

Table 7 – Top 10 most co-cited authors

Rank	Frequency	Centrality	Year	Author
1	15	0.01	2015	SCHOYEN, HALVOR
2	12	0	2020	MENG Q
3	11	0.06	2012	CORBETT JJ
4	11	0.01	2020	LASSERRE F
5	11	0	2019	WANG J
6	11	0.1	2012	NOTTEBOOM TE
7	10	0.07	2020	THEOCHARIS D
8	9	0.01	2019	LIU MJ
9	9	0	2020	OSTRENG W
10	8	0.03	2020	FAURY O

3.4 Hot research topics

Literature metrics often summarise research topics and identify research frontiers by calculating the co-occurrence frequency of keywords [70]. Keywords play a crucial role in summarising the main content of research, thus providing a more accurate overview of the studied field. To determine prominent research areas in canal transportation, this study utilises CiteSpace software for keyword co-occurrence analysis, where each node represents a keyword, with its size proportional to the co-occurrence frequency. The objective of this section is to utilise keyword contribution analysis and cluster analysis to elucidate the interconnections among keywords [71] and to answer Research question 2 (RQ2).

Based on the information provided by *Figure 8* and *Table 8*, we find that the main research hotspots in canal transportation can be categorised into two major types. Firstly, methodologically classified, "model" is the most commonly used approach in canal transportation research, typically developing models based on empirical data to facilitate simulation processes and methodological advancement [72]. This includes Bayesian network models [73–75], profit decision models [59], bilevel programming models [76] and other innovative open-source models [77, 78]. "Risk assessment" is a systematic methodology used to identify, analyse and evaluate various potential risks and uncertainties that may affect canal transportation operations and development. It is significant for accident prevention and enhancing waterway transportation safety [79] and provides effective references for decision-makers to ensure the safety of straits and canals [25]. Models and risk assessments are often closely linked in canal transportation research. Scholars analyse the impacts of their research objects by developing models, which are then used for risk assessment. Additionally, "competitiveness" is also a key research point. In canal transportation, scholars often determine the most competitive routes through comparisons and evaluations with different routes. This includes the most crucial transportation cost comparisons, followed by time, reliability and route characteristics, to select the optimal solution for waterway transportation [80]. Furthermore, discussions on "impacts" involve the interactions between waterway transportation and various aspects such as economic, policy, social, environmental and climate [28, 81–83].

Secondly, classified according to research objects, canal transportation, as a subset of "transportation" and "maritime transportation", is most mentioned by researchers in these two topics. Next, the Northern Sea Route and the Suez Canal are the most researched objects in canal transportation, especially the opening of the Southern Sea Route has effects on other canals and the choice among different waterway transports. This is usually combined with "climate change", particularly with the faster-than-expected melting of ice due to global warming, making research on the potential future opening of the Arctic route a popular topic [74, 84, 85]. Additionally, research topics related to the Suez Canal have strong research popularity in canal transportation. These topics include comparative studies between the Suez Canal and the Panama Canal [59, 85],as well as analyses of the impacts of the vessel grounding incident in March 2021. This event caused a disruption of critical global maritime transportation routes, highlighting the vulnerabilities within the global logistics supply chain [86].

Moreover, "China" as a keyword shows a certain research heat in the field of canal transportation. On the one hand, China's canal waterways play a crucial role in the logistics and transportation industry [87]. On the other hand, China has the most scholars in this field, who mainly explore China's canal waterway transportation. Some scholars focus on topics such as carbon emissions, energy policies and the Grand Canal transportation system [88, 89]. They also conduct in-depth analyses of specific regions such as the Zhenjiang Canal and the Xianghe Canal [90, 91]. Meanwhile, academic research also focuses on China's contemporary Maritime Silk Road, especially the risk assessment of the Suez Canal section and the assessment of coastal port competitiveness [26, 92]. Scholars also discuss the potential of Thailand's Kra Canal project for future trade potential and impact [93, 94], and study the potential impact of opening the Arctic route on China's canal transportation through the Suez Canal section [95], making China a popular research keyword in this field.

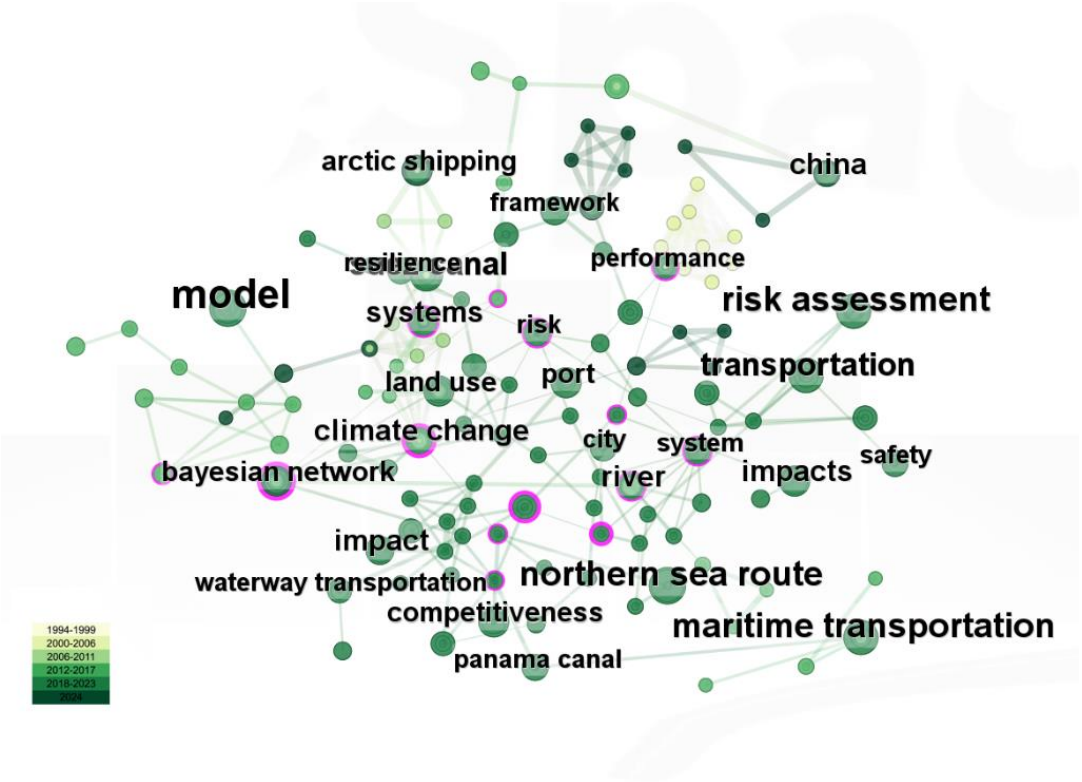

Figure 8 – A visualisation network map of co-occurrence analysis

Table 8 – Top 10 keywords ranked by co-citation counts

Rank	Frequency	Centrality	Year	Keywords
1	15	0.09	2007	Model
2	8	0.01	2018	Transportation
3	8	0.15	2018	Risk assessment
4	8	0.15	2016	Maritime transportation
5	7	0	2009	Northern Sea Route
6	6	0.11	2017	China
7	6	0.03	2010	Suez Canal
8	6	0.16	2009	Climate change
9	5	0	2018	Competitiveness
10	5	0.09	2020	Impacts

Understanding research trends and future directions is crucial for grasping the evolving landscape of canal transportation systems. This section, based on keyword contributions, identifies the top 15 keywords with the strongest citation bursts [96], aimed at addressing Research question 3 (RQ3).

Keywords play a pivotal role in delineating the dynamic changes and trending patterns within research domains. Examining keywords that are frequently cited and consistently mentioned can highlight the current frontiers of academic research. *Figure 9* illustrates the keywords experiencing the most significant citation growth, identifying the top 15 keywords with notable citation bursts during specific periods, represented by corresponding red lines. From *Figure 9*, we can discern the research frontiers in canal transportation, namely "risk assessment", "system" and "safety".

Amidst increasingly complex and variable transportation conditions, researching maritime transportation risks holds significant importance in preventing maritime accidents and enhancing maritime transportation safety [97]. Risk managers often select risk assessment techniques based on actual transport scenarios, management requirements and readily available data. In recent years, emerging analytical assessment methods in the risk domain include Markov chains, dynamic Bayesian, complex networks, knowledge graphs and others [79]. Moreover, "system" has emerged as an emphasised keyword in recent canal transportation research. Particularly, as methods for maritime transportation risk assessment are evolving towards systematisation and integration [79]. Its research scope not only encompasses maritime transportation systems (MTS) [97] but also canal systems, waterway allocation systems [98, 99], container port systems [100] and decision support systems in transportation [25]. Lastly, "safety" has also become a prominent keyword in current frontier research. Safeguarding the security of straits and canals plays a vital role in maritime transportation [25]. Recent research highlights discussions on various risk events such as ship collision accidents, adverse weather, military conflicts, piracy and terrorism, all aimed at ensuring safe transportation [87].

Thus, these relatively recent studies, as depicted in *Figure 9*, reflect that risk assessment, system analysis and safety assurance have emerged as the current research frontiers in the field of canal transportation. Furthermore, as transportation conditions and environments continue to evolve and change, these topics will continue to garner attention, driving advancements in the field.

Figure 9 – Top 15 keywords on canal transportation with the strongest citation bursts

4. CONCLUSION

Through the CiteSpace analysis of 212 publications related to canal transportation, this study aimed to provide a visual analysis of the research prospects and evolution in this field. Based on the analysis results, the following conclusions can be drawn.

Firstly, Lu, Jing, Yang, Zhifeng, Leitholdt, Eva and Zielhofer, Christoph, among others, are prolific authors in the field of canal transportation. In terms of citation impact, scholars such as Schoyen, Halvor, Meng Q, Corbett Jj, Lasserre F, Wang J and Notteboom Te have received significant citations for their research contributions. In terms of institutions, Dalian Maritime University, Chinese Academy of Sciences, Wuhan University of Technology and Shanghai Maritime University are core contributors to research in canal transportation. From a national perspective, China and the United States dominate research in this field, followed by countries such as Turkey and England. In terms of core journals, Maritime Policy & Management, Transportation Research Part E and Journal of Transport Geography serve as important platforms for publishing research in canal transportation, covering various aspects of the field including but not limited to the discipline itself, as well as discussions in environmental and economic disciplines.

Secondly, the hot topics in research on canal transportation mainly focus on two aspects. Firstly, discussions on analytical methods, focusing on models, risk assessment, competitiveness and impacts. Secondly, among the analysed objects, maritime transportation, the Northern Sea Route, the Suez Canal, climate change and

China have become popular research topics in canal transportation. Additionally, topics such as risk assessment, system analysis and safety have emerged as frontier research areas in this field.

These results provide researchers in the field of canal transportation with more systematic information, aiding in understanding the current research status and future development trends. Future research should focus on enhancing dynamic risk assessments for different waterway transport modes to ensure the safety of the entire transportation system, particularly in the case of canal systems. Additionally, this study has certain limitations, primarily due to the restriction of literature data sources to publications written in English, without analysing publications in other languages, which may lead to some degree of bias in understanding the research domain comprehensively.

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孙磊

运河交通运输的研究热点与前沿：基于 CiteSpace 的文献计量分析

摘要:
作为人工水道运输系统，运河在工业革命初期发挥了至关重要的作用，促进了更快速、便捷且经济高效的大规模货物运输，从而成为特定地区城市化与工业化进程中不可或缺的组成部分。本研究采用文献计量分析工具 CiteSpace，系统地分析了 Web of Science 数据库近 30 年来关于运河运输的 212 篇相关文献，旨在通过合作网络、共引网络、关键词共现及聚类模式的可视化表征，阐明该领域的知识体系结构。在研究结果中，我们建立了作者、机构和国家的合作网络，通过确定期刊共同引用网络，来揭示核心期刊的分布。文献共被引网络展示了运河运输的主要研究主题和知识结构，通过作者共引网络识别了有影响力的作者，通过关键词共现网络挖掘了研究热点和前沿。这项研究为运河运输的当前趋势和研究进展提供了全面而翔实的视角。此外，我们还提出了具有潜力的未来研究方向，以进一步推动该领域的全面发展。

关键词:
运河；人工水道；水道运输；运输；文献计量分析