# Trend and Hotspot Analysis of Waterway Transportation Safety Based on Bibliometrics

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**Abstract:** Waterway transportation safety (WTS) is the basis for waterborne transport and the key factor guaranteeing the sustainable development of transportation in the Waterway Silk Road. Based on the Web of Science database (formerly ISI Web of Knowledge) , this paper uses the bibliometric tool Histcite to carry out a systematic metrological analysis on the research of WTS, and compares the status quo and the focuses of this research domain at home and abroad, to grasp the dynamics and hot issues of current research. The results showed that the researches on WTS started as early as 1990, and the quantity of articles from internationally influential institutions in this domain, especially those form the US and China, presented an increasing trend. China's universities such as Wuhan University of Technology, Shanghai Maritime University and Dalian Maritime University have contributed greatly to the quantity of papers, but are lacking in innovative research achievements, important discoveries, and international influence. Developed countries such as Europe and the United States have, however, contributed more to the high quality of literature. The research hotspots in this field are focused on ship collision, model simulation, risk analysis and intelligent transportation systems.
**Keywords:** Waterway Transportation Safety; Bibliometrics; Research Trends.

## 1. INTRODUCTION

China's waterway transportation market and economy are rapidly developing and ceaselessly growing, with increasing water traffic density and more and more complicated navigation environment that seriously challenge the safety of waterway transportation, eliciting great concern of scholars at home and abroad [1]. At present, the major issues to be addressed for WTS include ship collision, stranding, etc. [2]. At the same time, the development of inland shipping is booming in recent years, benefiting from the rapid development of China's economy and the construction of the Inland River Economic Zones, especially in the Yangtze River Basin and the Pearl River Basin [3]. Notwithstanding the rapid growth, it cannot be overlooked that the inland river water transportation is characterized by the increase of navigation density and the trend of more and more large-scale vessels. The growing numbers of navigation-hampering facilities such as bridges and high-voltage cables across the fairway, the increasingly complex navigable environment and other substantive factors have caused multiple accidents jeopardizing WTS [4-5]. For example, on June 1, 2015, the passenger liner of the "Oriental Star" belonging to Chongqing Eastern Steamship Company was overturned, causing 442 deaths. On June 4, 2016, a shipwreck of the cruise ship “Shuanglong” in Guangyuan City, Sichuan Province claimed 13 deaths and 2 missing persons. These accidents all sounded the alarm for WTS management in China, which is therefore in extremely urgent need of research.

Bibliometrics, as an emerging discipline of quantitative analysis of bibliographic data based on mathematics, statistics and bibliography, explores the development trends and industry dynamics of the research field through systematic literature analysis, and provides theoretical direction and development ideas for scientific research and industry development [6]. Bibliometrics uses quantitative analysis to analyze the objective laws in the field of research and industry development, and adopts scientific measurement methods to analyze the research results in each research field, so as to grasp the latter's cutting-edge direction, research layout, and research strength [7]. So far, there has been no bibliometric analysis and research on WTS, and the existing review and analysis also lack detailed analysis and research on the current status and trends of research fields [8]. Therefore, this paper adopts bibliometrics method to dissect the research, development trends and hotspots in the research field of WTS, to provide reference for domestic researchers.

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## 2. DATA SOURCES AND ANALYSIS METHODS

In this paper, the Web of Science Database is used as a retrieval database for a comparatively systematic and comprehensive statistical analysis of relevant literature in the field of WTS. Science Citation Index (SCI) is a platform for scientific research achievement evaluation and literature retrieval approbated by scholars at home and abroad [9]. Generally speaking, the papers and publications included in SCI have representative, innovative basic & forward-looking topics in related fields, and a greater influence in the international context. Our search and analysis are firstly based on Web of Science's own literature analysis tool. The search time is as of November 15, 2017, and the time span is all years. With reference related researches, we decide as citation databases the Science Citation Index Expand (SCIEXPAND) -1900 to date, Social Sciences CitationIndex (SSCI) -1900 to present, Conference Proceedings Citation Index - Science (CPCI-S) - 1997 to date, and Emerging Sources Citation Index (ESCI) --2015 to date. This paper mainly uses Excel software and SCI literature statistical analysis software Histcite 12.03.17 (Official Website Download Link: http://interest.science.thomsonreuters.com/forms/HistCite/ ) . Histcite software analyzes the general development trends and research hotspots in this research field via the citation database Recs (number of literature), TLCS (Total Local Cite Score: Sum of the Times Cited in local research field), and TGCS (Total Global Cite Score).

To prevent omissions, this paper takes WTS as the research object, and designs multiple logical relation search formulas to ensure the completeness of document retrieval, reduce the errors of subsequent analysis, and reflect the actual situation of research in this field. With the above groundwork, the results of the bibliographic retrieval are shown in Table 1. As can be seen from Table 1, a total of 430 research papers are related to WTS as per different search methods. Taking into account that any single search topic may result in the loss of the number of retrieved documents and greater uncertainty for subsequent analysis, this paper thus focuses on the analysis of the results of the search formula #4, with a total of 430 articles.

**Table 1: SCI search results based on different search formulas**

| No. | Search formula | Number of documents (Recs) | Number of document types |
|---|---|---|---|
| #1 | TS = (marine traffic safety*) | 135 | 3 |
| #2 | TS = (water traffic safety*) | 325 | 5 |
| #3 | TS = (waterborne traffic safety* ) | 5 | 2 |
| #4 | TS = (#1 or #2 or #3) | 430 | 5 |

Note: TS represents “topic sentences”.

## 3. RESULTS AND DISCUSSION

### 3.1. Analysis of Development Trends of WTS Literature

All the papers in the SCI are subject to type-specific descriptive statistics, as shown in Table 2, research papers and conference papers took the lion's share (97.21% in total) in WTS-related SCI articles. The earliest WTS-related document was published on Accident Analysis and Preventation in 1990 by HASHIMOTO of Tsukuba University in Japan [10]. Research on WTS has since gradually developed. Many scholars have begun to set foot in this field, and related research has been on the rise, with more and more articles published in international authoritative magazines.

**Table 2: Types and proportions of WTS-related documents**

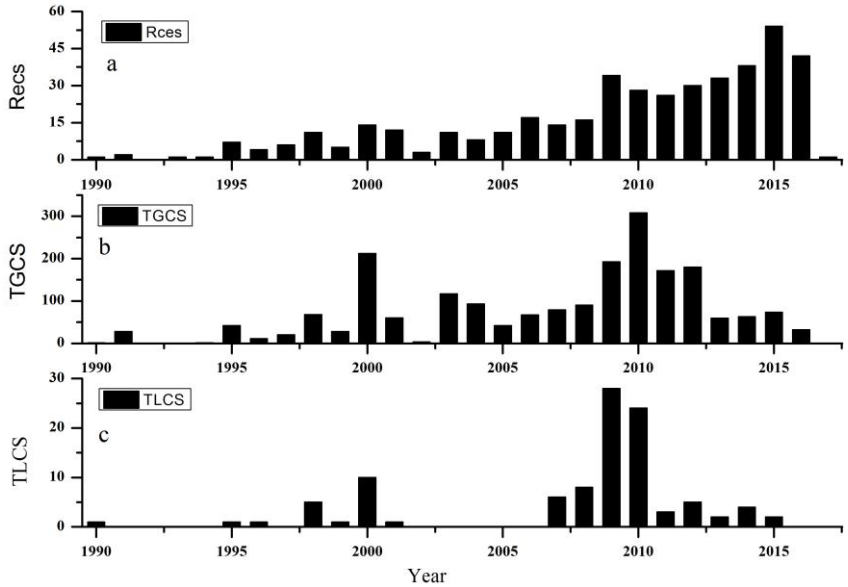
| Document type | Number of documents (Recs) | Percentage (%) |
|---|---|---|
| Articles (research papers) | 234 | 54.42 |
| Proceeding Paper (Conference Paper) | 184 | 42.79 |
| Review | 10 | 2.33 |
| Note (transcript) | 1 | 0.23 |

| | | |
|---|---|---|
| Letter | 1 | 0.23 |

It can be seen from Figure 1 that the development of WTS-related literature can be divided into three major phases. The first phase, dating from 1990 to 2000, marks the initial stage of research on WTS. At this stage, Recs (number of documents) basically remained in single digits per annum, exceeding 10 for the first time in 1998. The slow growth may be attributable to the relatively small number and less eye-catching water traffic accidents during this period. The second stage dates from 2001 to 2010, during which the number of documents gradually increased and topped 18 articles per annum. TGCS and TLCS have also shown an increasing trend at this stage, which may be ascribable to the fact that since the beginning of the 21st century, the water transportation economy saw a rapid development with nearly 80% of the world merchandise trade volume being actualized via maritime transport; whereas the defective WTS policies and regulations have led to a number of marine traffic accidents, resulting in significant property damage and casualties. The countries have thus become aware of the seriousness of WTS and the importance of carrying out research on WTS, this has laid the foundation for the innovative development of WTS-related scientific research, which has since witnessed prioritized development and ceaseless emergence of important documents. The third stage dates from 2011 to the present, and the total amount of research literature related to WTS is still in an ever-increasing process. However, it can be seen from Figure 1(b, c) that indicators such as TGCS and TLCS have shown a declining trend. In particular, TLCS has a particularly significant downward trend, which may be due to the following three points: (1) Research in this area has become more mature, and related research priorities have begun to shift; (2) the transportation structure has gradually shifted from water transport to road and air transport, thus the related research in the field of WTS has received less attention; (3) The publication of documents at this stage was relatively late, resulting in a decline in the relevant citation rate.

In general, researchers in Europe and the United States have pioneered the research on WTS. China's related research started relatively late, the first domestic WTS research literature was not published until in 2004 [11].

**Figure 1: Annual publications and citations for WTS**




(a) Recs; (b) TLCS; (c) TGCS. Recs denotes the number of documents, TLCS and TGCS refer to the Total Local Cite Score and in all global documents of the SCI, respectively.

### 3.2. Nationality-specific and institution-specific analysis of authors

Since the 21st century, research in the field of WTS has been on the rise with participants from 57 countries and regions. As can be seen from Table 3, of the 24 countries and regions with the largest WTS-related publications: (1) research on WTS is mainly distributed in Europe, America, Asia, and

Africa, and mostly in Europe, America, and Asia. Europe countries' publications account for 20% of the total, and those of Asian countries account for 30% of the total publications. Among them, China and the United States have more publications in this field than other countries; (2) China, Singapore, and Finland are the top three regarding TLCS; (3) the United States has the highest TGCS of 373. This shows that in the field of WTS research, China is leading in the quantity of Recs, and the United States is in leading in the quality of Recs. In addition, the analysis of the average total local citation scores (TLCS/Recs) and the average total global citations scores (TGCS/Recs) found that some Nordic countries such as the United Kingdom, Finland, and Denmark reached 0.6 (TLCS/Recs) and 15 (TGCS/Recs) or more respectively, surpassing by far those of China and the United States, indicating that some European countries' WTS Research has been recognized by peers and has attracted a great deal of attention due to the high quality of its literature. Whereas, China's domestic publications is well below that of the European countries and the United States, it may be attributable to the relatively late start and the time lag of China's research in this field, which also reflects the lack of attention paid by domestic peers to research in this field. In addition, the Histcite findings reveal that the affiliations of 66 authors (accounting for 15.3% of the total document volume) are unknown, the Nationality of the document has thus become obscured, causing some errors in the analysis results.

**Table 3: Statistics of publications by Country/Region on WTS Studies**

| No. | Country | Number of documents (Recs) | TLCS/times | TGCS/times | TLCS/Recs | TGCS/Recs |
|---|---|---|---|---|---|---|
| 1 | Peoples R China | 80 | 22 | 185 | 0.28 | 2.31 |
| 2 | USA | 65 | 7 | 373 | 0.11 | 5.74 |
| 3 | Italy | 20 | 1 | 110 | 0.05 | 5.50 |
| 4 | UK | 18 | 11 | 270 | 0.61 | 15.00 |
| 5 | Canada | 16 | 2 | 136 | 0.13 | 8.50 |
| 6 | Japan | 16 | 2 | 21 | 0.13 | 1.31 |
| 7 | Germany | 14 | 0 | 55 | 0.00 | 3.93 |
| 8 | Poland | 14 | 0 | 21 | 0.00 | 1.50 |
| 9 | South Korea | 13 | 0 | 34 | 0.00 | 2.62 |
| 10 | Turkey | 13 | 4 | 57 | 0.31 | 4.38 |
| 11 | Australia | 12 | 0 | 46 | 0.00 | 3.83 |
| 12 | Netherlands | 12 | 7 | 91 | 0.58 | 7.58 |
| 13 | Singapore | 11 | 19 | 76 | 1.73 | 6.91 |
| 14 | Taiwan | 10 | 5 | 66 | 0.50 | 6.60 |
| 15 | Spain | 9 | 1 | 59 | 0.11 | 6.56 |
| 16 | Finland | 7 | 19 | 155 | 2.71 | 22.14 |
| 17 | Croatia | 6 | 0 | 1 | 0.00 | 0.17 |
| 18 | Lithuania | 6 | 1 | 16 | 0.17 | 2.67 |
| 19 | Denmark | 5 | 0 | 96 | 0.00 | 19.20 |
| 20 | Egypt | 5 | 0 | 17 | 0.00 | 3.40 |
| 21 | Greece | 5 | 1 | 18 | 0.20 | 3.60 |
| 22 | Switzerland | 5 | 0 | 22 | 0.00 | 4.40 |
| 23 | Brazil | 4 | 0 | 3 | 0.00 | 0.75 |
| 24 | India | 4 | 0 | 6 | 0.00 | 1.50 |

To analyze the distribution of WTS research, the author conducted further categorization of research institutes in various countries: a total of 427 research institutes around the world have engaged in research on water transportation safety. Among the top 30 research institutes, there are as many as 11 research institutes in China (Wuhan University of Technology, Shanghai Maritime University, Dalian

Maritime University, etc.), accounting for 36%, while those of the European countries and America account for 40% of the total. Among them, Wuhan University of Technology and the National University of Singapore have more publications (with 14 and 11 papers, respectively), this has much to do with the unique and complex geographical location of waters and sustained input for scientific research [12]. The Yangtze River is the third longest river in the world. Wuhan is located in a well-developed shipping area in the upper and middle reaches of the Yangtze River. Given the above, greater convenience has been provided for the development of WTS research in Wuhan, China [13]. Singapore is located at the junction of the Straits of Malacca and the Karimata. Water transport is of utmost importance. The government's strong research funding and excellent science education have contributed to the outstanding results of WTS-related research [14].

**Table 4: Publications in the field of waterway transportation safety in branch institutions**

| No. | Branch institutions | Number of documents (Recs) | TLCS /times | TGCS/ times |
|---|---|---|---|---|
| 1 | Natl Univ Singapore, Dept Civil & Environm Engn (Department of Civil and Environmental Engineering, National University of Singapore) | 9 | 19 | 69 |
| 2 | Shanghai Maritime Univ, Marine Merchant Coll (Merchant Marine College of the Shanghai Maritime University) | 6 | 0 | 3 |
| 3 | Dalian Maritime Univ (Dalian Maritime University) | 3 | 5 | 20 |
| 4 | Natl Kaohsiung Marine Univ, Dept Shipping Technol (Department of Shipping Technology, National Kaohsiung Maritime University) | 3 | 4 | 27 |
| 5 | Natl Univ Singapore, Ctr Maritime Studies (Center of Maritime Studies of the National University of Singaporer) | 3 | 6 | 25 |
| 6 | Univ Roma Tor Vergata, Dept Elect Engn (Department of Elective Engineering, University of Rome Tor Vergata) | 3 | 0 | 2 |
| 7 | Univ Wisconsin, Dept Civil & Environm Engn (Department of Civil and Environmental Engineering, University of Wisconsin) | 3 | 2 | 46 |
| 8 | Beijing Jiaotong Univ, Sch Civil Engn (School of Civil Engineering, Beijing Jiaotong University) | 2 | 0 | 17 |
| 9 | Dalhousie Univ, Dept Ind Engn (Department of Industrial Engineering, Dalhousie University) | 2 | 1 | 10 |
| 10 | Korea Adv Inst Sci & Technol, Dept Civil & Environm Engn (Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology) | 2 | 0 | 11 |
| 11 | Lakehead Univ, Dept Civil Engn (Department of Civil Engineering, Lakehead University) | 2 | 0 | 14 |
| 12 | Marquette Univ, Dept Civil & Environm Engn (Department of Civil and Environmental Engineering, Marquette University) | 2 | 1 | 45 |
| 13 | Natl Res Council Canada, Inst Res Construct (Construction Research Institute, National Research Council Canada) | 2 | 0 | 27 |
| 14 | Natl Taiwan Ocean Univ, Dept Elect Engn (Department of Elective Engineering, National Taiwan Ocean University) | 2 | 1 | 28 |
| 15 | Natl Taiwan Ocean Univ, Dept Merchant Marine (Department of Merchant Marine, National Taiwan Ocean University) | 2 | 4 | 35 |
| 16 | Politecn Torino, Dipartimento Elettron (Polytechnic University of Turin) | 2 | 1 | 13 |
| 17 | Wuhan Univ Technol, Intelligent Transport Syst Res Ctr (Intelligent Transport System Research Center, Wuhan University of Technology) | 2 | 0 | 0 |
| 18 | Wuhan Univ Technol, Sch Logist Engn (School of Logistics Engineering, Wuhan University of Technology) | 2 | 0 | 0 |
| 19 | Wuhan Univ Technol, Sch Nav (School of Shipping, Wuhan University of Technology) | 2 | 0 | 0 |
| 20 | Wuhan Univ Technol, Sch Transportat (School of Transportation, Wuhan University of Technology) | 2 | 0 | 0 |

For more detailed investigations on various research institutions, the author conducted further analysis on the branches of research institutions, the results are shown in Table 4. Among them, there are 618 branch institutions for WTS research, including the Department of Civil and Environmental Engineering, National University of Singapore; Merchant Marine College of the Shanghai Maritime University; Department of Shipping Technology, National Kaohsiung Maritime University; Center of Maritime Studies of the National University of Singapore, etc. Of the top 20 branch research institutes, 13 are from Asia, including China's Merchant Marine College of the Shanghai Maritime University, Dalian Maritime University and the School of Civil Engineering of Beijing Jiaotong University. China's Wuhan University of Technology has more branch institutes on WTS research, more extensive research findings, and greater contribution to the WTS publications. However, compared with foreign research institutes, the TLCS and TGCS of China's research institutes are far below. This shows that the research results of China's domestic research institutes in this field have not attracted the attention of the world's peers, and the quality of their publications also lags far behind that of the Europe and the United States and some Asian countries.

### 3.3 Analysis of the results based on publication source

Research journals can, to a certain extent, reflect the distribution characteristics, levels and quality of published documents. Through database statistics, there are currently 334 publications related to WTS, of which the top 20 Journals are shown in Table 5. The Journals with a large number of WTS publications include 《Journal of Navigation》, 《Transportation Research Record》, and 《Safety Science》. Among them, 《Journal of Navigation》is a bimonthly publication with about 20 articles per issue, but its impact factor is only 1.267, relatively lower than the other Journals, and the reason for its being selected by a large number of researchers may be that the Journal is more concerned with new discoveries in the research field and has a shorter publication period. The Journal's higher ranking of TLCS and TGCS indicates that it has high reputation and recognition in the industry. However, the local citation rate of Journals with high impact factors is not necessarily high. As shown in Table 5, the impact factor of 《Science of The Total Environement》is close to 4, but its TLCS and TGCS are not high. The main reason for this is that WTS is not the focus research field of this Journal. The 《Reliability Engineering & System Safety》, 《Risk Analysis》, and 《Safety Science》Journals focus on the study of waterway traffic safety risks, etc., and are more recognized by researchers in this field, and their average TLCS/Recs are also higher, indicating that these journals are prone to be valued by industry researchers. Among them, the TLCS/Recs of 《Risk Analysis》 is as high as 5, marking it as an important Journal in the field of WTS.

**Table 5: Top 20 Journals on waterway transportation safety studies**

| No. | Journal Name | Number of WTS documents | Impact factor | Larger class partition | TLCS /times | TGCS/times | TLCS/ Recs |
|---|---|---|---|---|---|---|---|
| 1 | JOURNAL OF NAVIGATION | 21 | 1.267 | 4 | 28 | 166 | 1.33 |
| 2 | TRANSPORTATION RESEARCH RECORD | 16 | 0.522 | 4 | 5 | 38 | 0.31 |
| 3 | SAFETY SCIENCE | 12 | 2.157 | 2 | 5 | 69 | 0.42 |
| 4 | ACCIDENT ANALYSIS AND PREVENTION | 5 | 2.07 | - | 4 | 52 | 0.80 |
| 5 | RELIABILITY ENGINEERING & SYSTEM SAFETY | 4 | 2.489 | 2 | 18 | 170 | 4.50 |
| 6 | SCIENCE OF THE TOTAL ENVIRONMENT | 4 | 3.976 | 2 | 1 | 46 | 0.25 |
| 7 | WATER SCIENCE AND TECHNOLOGY | 4 | 1.064 | 4 | 1 | 55 | 0.25 |
| 8 | JOURNAL OF MARINE SCIENCE AND TECHNOLOGY-TAIWAN | 3 | 0.298 | 4 | 4 | 35 | 1.33 |
| 9 | MARINE POLICY | 3 | 2.453 | - | 0 | 3 | 0.00 |
| 10 | RISK ANALYSIS | 2 | 2.225 | 1 | 10 | 66 | 5.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 11 | ANNUAL REVIEWS IN CONTROL | 2 | 2.042 | 3 | 0 | 36 | 0.00 |
| 12 | CANADIAN JOURNAL OF CIVIL ENGINEERING | 2 | 0.586 | 4 | 0 | 28 | 0.00 |
| 13 | EXPERT SYSTEMS WITH APPLICATIONS | 2 | 2.981 | 2 | 1 | 27 | 0.50 |
| 14 | JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING | 2 | 1.696 | 3 | 0 | 20 | 0.00 |
| 15 | BALTIC JOURNAL OF ROAD AND BRIDGE ENGINEERING | 2 | 0.519 | 4 | 0 | 14 | 0.00 |
| 16 | PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS-WATER MANAGEMENT | 2 | 0.656 | 4 | 0 | 14 | 0.00 |
| 17 | TUNNELLING AND UNDERGROUND SPACE TECHNOLOGY | 2 | 1.741 | 3 | 0 | 9 | 0.00 |
| 18 | IEEE AEROSPACE AND ELECTRONIC SYSTEMS MAGAZINE | 2 | 0.611 | 4 | 0 | 8 | 0.00 |
| 19 | ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH | 2 | 2.76 | 3 | 0 | 4 | 0.00 |
| 20 | MARINE TECHNOLOGY SOCIETY JOURNAL | 2 | 0.59 | - | 0 | 4 | 0.00 |

### 3.4 Analysis of Core Authors

Of the 430 documents retrieved from the Web of Science database, there were a total of 1,252 authors, among which 1,227 published less than 2 (including 2) papers in the field. As per the Price's law (as follows), the minimum publications by the core author can be obtained, as shown in formula (1):

$$M=0.749\sqrt{n_{max}} \quad (1)$$

$n_{max}$ refers to the number of papers published by the author with the highest publications. In this study, $n_{max}$ =5, so M takes the largest integer 2.

The statistical results show that there are 25 authors with more than 2 articles published in the field, accounting for 2% of the total number of authors, and the core authors have a total number of 249 articles, accounting for 57.9% of the total, which is in line with Price's law, viz., the total number of papers published by the core authors should account for more than half of all papers published [15]. Prof. Chin and Prof. Debnath from the Department of Civil Engineering at the National University of Singapore enjoy the highest WTS publications, which are mainly focused on ship collision risk assessment and model simulation [16-20]. Most of the core authors in the WTS field come from Asia. As shown in Table 6, nearly 60% of the top 20 authors of WTS paper publications are from Asia, and especially, from Singapore and China. Singapore has 4 and Mainland China has 6 authors in the top 20, indicating their strong scientific research capabilities. Of the 6 major authors of WTS research in Mainland China, 4 authors are from the Shanghai Maritime University, the other two are from Wuhan University of Technology and Zhejiang Ocean University, respectively. The main researchers in Europe are from Italy and Finland, indicating a remarkable relationship with their unique geographical conditions and frequent maritime trade [21]. The core authors of WTS in U.S. are mainly from the Department of Civil and Environmental Engineering at the University of Wisconsin.

**Table 6: Top 20 authors in the field of WTS**

| No. | Author | Publications /papers | TLCS /times | TLGS /times | Research Unit |
|---|---|---|---|---|---|
| 1 | Chin HC | 5 | 12 | 43 | Department of Civil Engineering, National University of Singapore |
| 2 | Debnath AK | 5 | 12 | 43 | Department of Civil Engineering, National University of Singapore |
| 3 | Kujala P | 5 | 19 | 143 | Department of Applied Mechanics, University of Helsinki |
| 4 | Zhang H | 5 | 0 | 16 | Merchant Marine College, Shanghai Maritime University |
| 5 | Galati G | 4 | 0 | 2 | Department of Elective Engineering, University of Rome Tor Vergata |

| | | | | | |
|---|---|---|---|---|---|
| 6 | Hu SP | 4 | 0 | 3 | Merchant Marine College, Shanghai Maritime University |
| 7 | Pavan G | 4 | 0 | 2 | Department of Elective Engineering, University of Rome Tor Vergata |
| 8 | Weng JX | 4 | 6 | 23 | School of Civil and Environmental Engineering, National University of Singapore |
| 9 | Hanninen M | 3 | 12 | 82 | Department of Applied Mechanics, Aalto University |
| 10 | Tsou MC | 3 | 5 | 47 | Department of Transportation and Maritime Sciences, National Taiwan Ocean University |
| 11 | Noyce DA | 3 | 2 | 46 | Department of Civil and Environmental Engineering, University of Wisconsin |
| 12 | Qin X | 3 | 2 | 46 | Department of Civil and Environmental Engineering, University of Wisconsin |
| 13 | Meng Q | 3 | 6 | 25 | School of Civil and Environmental Engineering, National University of Singapore |
| 14 | Rajani B | 3 | 0 | 34 | Construction Research Institute, National Research Council Canada |
| 15 | LeBlanc LA | 3 | 1 | 26 | School of Business Administration, University of Arkansas |
| 16 | Jung S | 3 | 0 | 15 | Department of Civil and Environmental Engineering, University of Wisconsin |
| 17 | Yan XP | 3 | 0 | 9 | Intelligent Transport System Research Center, Wuhan University of Technology |
| 18 | Li S | 3 | 0 | 5 | Merchant Marine College, Shanghai Maritime University |
| 19 | Zhang JP | 3 | 0 | 2 | Merchant Marine College, Shanghai Maritime University |
| 20 | Liu XZ | 3 | 0 | 1 | School of Oceanography, Zhejiang Ocean University |

### 2.5 Result of the analysis of research hotspots

This paper analyzes the main research directions in the field through the statistical function of Web of science. The result shows that the research field of WTS involves engineering (59.82%), transportation science (15.45%), environmental science (11.48%), Oceanography (11.04%), Countermeasures Research Management (5.96%), Materials Science (5.52%) and other disciplines, many of which are basic disciplines and their corresponding extensions, indicating that the research on WTS is based on engineering and other basic disciplines with multidisciplinary and extensive features.

The tracking of the development trend and hotspots in a research field can be quickly located by the LCR (local cited references) values of the cited documents. This is because an oft-cited documents in a local database indicates a higher degree of attention it has attracted in the searched literature, thus it indicates a hot spot of research. Histcite's drawing function was used to draw the citation map, and the top 50 LCR values were analyzed, as shown in Figure 3, where the ordinate represents the year of publication, the squares represent the documents in the local database, the number in the square represents the serial number of the document in the database. The larger the square, the higher the local reference rate of the document will be. According to Fig. 3, the links between the documents are separated into two large blocks, namely, there are two main branches of research on WTS: the first branch focuses on the assessment of WTS risks, including model simulation, etc.; the second branch focuses on Traffic Safety Risk Assessment of Ports and Inland Rivers. The documents of the two branches are mainly aim at ship collisions and model simulations, indicating that ship collisions are the areas of greatest concern in the study of WTS. The word frequency analysis of the literature keywords is also an important method for the analysis of key research areas. As shown in Table 7, the key areas of research on WTS include ship collisions [22], marine accidents [23], ships [24], ports [25], Risks [26], model simulation [27], safety [28], accidents [29], ship identification system [30], etc. Through the analysis of word frequency of key words in the past five years, the results show that ship collisions, model simulations, risk analysis, intelligent transportation systems, etc. are the recent hot spots in this field. They are also important for researchers, especially domestic practitioners, in the future direction.

**Figure 3: Citation map of local cited references in the area of waterway transportation safety**

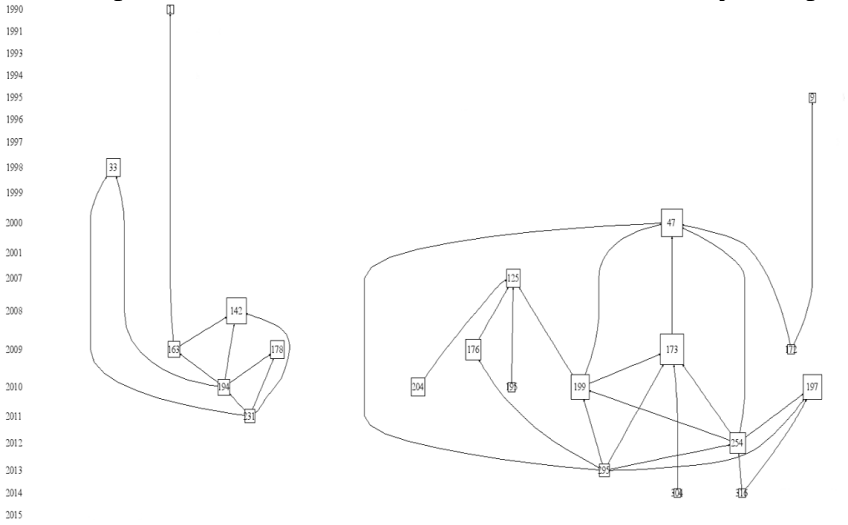



**Table 7: Key Word Frequency for Articles with Top 20 LCR Values**

| No. | Key word | Word frequency | No. | Key word | Word frequency |
|---|---|---|---|---|---|
| 1 | COLLISION | 35 | 11 | RISKS | 14 |
| 2 | TRAFFIC | 34 | 12 | ACCIDENTS | 13 |
| 3 | MARINE | 22 | 13 | ANALYSIS | 13 |
| 4 | SHIP | 22 | 14 | FINLAND | 11 |
| 5 | PORT | 21 | 15 | GULF | 11 |
| 6 | RISK | 21 | 16 | USING | 11 |
| 7 | VESSEL | 18 | 17 | WATERS | 11 |
| 8 | AVOIDANCE | 16 | 18 | DATA | 10 |
| 9 | MODELING | 16 | 19 | STRAIT | 10 |
| 10 | SAFETY | 15 | 20 | AIS | 9 |

Based on the keyword frequency, the development trend in the field of WTS was further analyzed. Substantial researches have been done outside China for ship collisions with major research directions focused in close range collision avoidance, collision warning systems, and automatic collision avoidance for ships. Andressen established the expert system Munin (Muscle and Nerve Inference Network) using the Bayesian network as early as 1989 [31]. Based on Bayesian network research, Friis-Hansen P further analyzed the causes of ship collision accidents and used HUGIN software for system simulation. Based on the principle of traffic conflict technology to classify traffic conflicts through conflict severity levels, Weibin Zhang et al. (2015) proposed a novel maritime traffic data screening model that is particularly suitable for use in offshore and coastal restricted sea areas to avoid ship collisions [32]. At present, research on ship collisions has been developed in the field of artificial intelligence outside China. Large databases and model simulations are used to avoid ship collisions and ensure navigation safety. China's domestic research on ship collision started late, and gradually developed from the initial collision analysis to the computer-aided collision avoidance system. Yu Pingting and others used the Bayesian network model to analyze ship collision accidents. Based on the accident causality theory, a three-layer Bayesian network model based on "risk factor - accident - hazard" was proposed. The model nodes, the structure of each layer of the model, the correlation between layers, and the ways to build a network model are described in detail [33]. Ni Shengke, Liu Zhengjiang et al. (2017) proposed an MPGA (multi-population genetic algorithm)-based ship collision avoidance assistant decision-making method, which utilizes the knowledge of ship collision avoidance and heuristics to dynamically generate optimal collision avoidance paths [34]. In recent years, with the rapid development of China's science and technology and the government's increasing emphasis on shipping safety, research on ship collisions has also been developed toward integrated, technology-based, and diversified directions.

Regarding the research on risks and safety, Denmark and Sweden started seminars on the safety of navigation in the Öresund Strait as early as in 2005. The Royal Danish Administration of Navigation and Hydrography, the Danish Maritime Authority and the Swedish National Maritime Administration jointly set up research working groups for in-depth study on this topic. With the cooperation of the two governments, Automatic Identification System (AIS) has been used to establish underlying data base for accidents such as collisions and stranding, and risk analysis methods such as Formal Safety Assessment (FSA) have been used to analyze the damage to human life, property, and the environment by collision and stranding accidents in the Öresund Strait. The ship collision, grounding probability model and consequence analysis model have been established, to furnish measures to reduce the risk of strait accidents as per the characteristics of the Öresund Strait and cost-effectiveness principles [35]. Floris Goerlandt and Jakub Montewka (2015) proposed a risk analysis framework for marine transportation systems and used risk analysis as a tool for decision support. A Bayesian Network (BN) modeling is applied for probabilistic risk quantification. On this basis, uncertainty judgments were made in the subsequent risk analysis phase with global data [36]. The research on safety risks in foreign countries was carried out earlier and focused on accident risk analysis and risk reduction measures. Recently, more emphasis was placed on risk model simulation and uncertainty of risk analysis. China has done a lot of research on safety risks. Zhang Di and Zhang Jinfen et al. (2014) proposed a risk method that combines fuzzy rules and evidence reasoning to solve the navigation evaluation problem of inland water transport systems under uncertain conditions [37]. Wu Changyue (2016) used the genetic neural network model to make an effective assessment of the transport of dangerous goods in waterways, to reasonably determine the risk degree of cargo transportation in ships carrying dangerous goods [38]. Huang Chung et al. (2017) used IWRAP MK II software to simulate ship collision risk in specific waters, and underwater topographic maps to analyze the area and time of high incidence of ship collision accidents [39]. In recent years, from the perspective of safety risk management, China's research on safety risks has studied countermeasures and established a system for prevention & control of water traffic risks, and improved management mechanisms to reduce the probability of water traffic accidents. The research on the safety risks of dangerous goods transported on water, and the transportation of dangerous goods on water has become a hot spot in China's research. In-depth studies have been made on the use of dangerous goods packaging, technical measures for safety management, risk assessment, accident emergency response, risk prevention & control system, multimodal transport risk control, and the types of dangerous goods prohibited from transportation, etc.

In general, studies on waterway safety in China mainly focus on the establishment of safety risk prevention & control system, the causes and prevention of accidents, the R&D of ship collision identification systems using databases, and the research on the safety risks of dangerous goods transport. There are more mature foreign studies in these areas, where the research focuses have also begun to shift to the use of mature sophisticated models to study close range collision avoidance, etc. Compared with foreign countries, China is a late-starter in WTS research, and conducted research on computer-aided collision avoidance only recently, but remarkable achievements have been made in the research on the control of safety risk of dangerous goods transported on water to effectively escalate the corresponding safety levels in China. The follow-up studies shall focus on strengthening the research on the ship's close range collision avoidance, risk early warning system and other hot spots.

## 4. CONCLUSIONS AND PROSPECTS

From the perspective of bibliometrics, this paper makes a detailed analysis of the research field of WTS based on the Web of sciences database in SCI. Through the comparison of the interannual changes of published literature, and the analysis of different countries and institutions, sources of publications, and core authors, the hotspots and trends of WTS research are discussed. The results show that some European countries such as Finland have a relatively higher level of research in the area of WTS. They take the lead in TLCS/Recs and TGCS/Recs in comparison with other countries and thus attracted a greater degree of attention in the academia. The United States has started earlier in the field of WTS research and has relatively strong overall strength, the WTS-related research is

mainly conducted by the University of Wisconsin. The core authors in this domain are mainly from some Asian countries such as Singapore and China, as well as from Europe and the United States. The research directions focus primarily on the evaluation of maritime, port and inland river traffic safety risks, wherein ship collision simulation assessment and intelligent waterway traffic information systems are the hot spots in this field.

Although China's total publication in this field ranks the first in the world, as a late comer, China remains relatively backward in domestic WTS research. There is still a great margin for improvement of the quality of its published papers and the construction of research teams. Shanghai Maritime University, Wuhan University of Technology and other institutions have strong scientific research strength in China, but there is still some deficiency in the level and depth of research. Therefore, to improve China's scientific strength in WTS research, the following suggestions are given to provide reference for decision-making in this field.

(1) Based on the existing research and foreign experience, development plan shall be made to gradually deepen the WTS research, and formulate a scalable method for WTS risk evaluation in China.

(2) Actively conduct exchange studies with foreign advanced scientific research institutions to track the current WTS research trends and hotspots, and at the same time, accelerate the progress of domestic in-depth WTS scientific research while taking into account the characteristics of China's water transport and different water areas.

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