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Application of Group Decision Making in Shipping Industry 4.0: Bibliometric Analysis, Trends, and Future Directions

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Abstract: With the development of Internet technologies, the shipping industry has also entered the Industry 4.0 era, which is the era of using information technology to promote industrial change. Group decision making (GDM), as one of the key methods in decision science, can be used to obtain optimal solutions by aggregating the opinions of experts on several alternatives, and it has been applied to many fields to optimize the decision-making process. This paper provides an overview and analysis of the specific applications of GDM methods in Shipping Industry 4.0, and discusses future developments and research directions. First, the existing relevant literature is analyzed using bibliometrics. Then, the general procedure of GDM is investigated: opinion/preference representation, consensus measure, feedback mechanism, and the selection of alternatives. Next, the specific applications of GDM methods in Shipping Industry 4.0 are summarized. Lastly, possible future directions are discussed to advance this area of research.

Keywords: group decision making; consensus; Shipping Industry 4.0; bibliometric

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1. Introduction

Following Industry 1.0 (the age of the steam engine), Industry 2.0 (the age of electrification), and Industry 3.0 (the age of information technology), the term "Industry 4.0" was introduced to the public at the Hannover Messe in [1]. The Industry 4.0 era relies on new technologies such as mobile computing, the Internet of Things, big data, and artificial intelligence to integrate digital cyber–physical production systems with processes and stakeholders, which, in turn, supports the digital and intelligent development of industry [2]. In the era of Industry 4.0, machines and products are interconnected, intelligent components that can exchange local and global data across corporate boundaries in an application scenario where data transparency and flexibility are greatly enhanced [3] while reducing error rates in the workplace, increasing efficiency and labor productivity, and enabling new digital-service-based business models. The transformation of the shipping industry can be achieved by integrating digital and intelligent technologies in the design, development, construction, operation, and service of ships, i.e., the development of Shipping Industry 4.0 [4]. The development of Shipping Industry 4.0 can improve the ability of shipping-related enterprises to respond to market trends, reduce the operating costs of all segments of the shipping industry chain, and accelerate the development of the shipping industry. Therefore, it has received extensive attention from scholars.

Decision science is used in various fields as a method for identifying uncertainty and inferring optimal decisions. Group decision making (GDM), an important component of decision science, can improve the scientificity of decision making by aggregating multiple experts' evaluation information on several alternatives to select the optimal solution [5]. Research on GDM has become a hot spot in recent years, and many researchers have applied GDM methods to different fields, such as public transportation development [6–8] and the circular economy [9,10]. At the same time, the GDM method has been increasingly widely applied in Shipping Industry 4.0 in recent years. For example, Cao et al. [11] used an interactive GDM method for star-rate cruise ships and offered recommendations on how to improve their service capabilities and star ratings. Liu et al. [12] used the GDM method on the basis of granular computing and a social network to evaluate the performance of container liners. GDM can enhance intelligence and accuracy in Shipping Industry 4.0 by using “group intelligence” to provide more complete information on the advantages and disadvantages of alternative solutions and to increase the acceptability of the decision results. Applying GDM methods to Shipping Industry 4.0 can improve the efficiency and quality of the involved decisions, and the shipping industry’s ability to control risk and develop sustainably.

A number of existing studies reviewed the GDM and Shipping Industry 4.0 literature. For example, for the review of GDM, Morente-Molinera et al. [13] reviewed the multi-granularity fuzzy language modeling approach in GDM. Wang et al. [14] analyzed the progress of fuzzy preference modeling methods in GDM. For the review of Shipping Industry 4.0, Stanic et al. [15] reviewed academic and industrial advances in the development of Shipping Industry 4.0. Sepehri et al. [16] examined the impact of Shipping Industry 4.0 on the control of shipping accidents. However, the aforementioned literature does not summarize and analyze the application of GDM methods in Shipping Industry 4.0, nor does it use bibliometric analysis. Therefore, the motivation and aim of this paper are to use bibliometrics to review the application of GDM methods in Shipping Industry 4.0, to fill the research gap in this field, to help scholars in understanding the hot spots of research in this field so far, and to help shipping companies in finding targeted solutions to their difficulties. In addition, bibliometrics is based on quantitative analysis [17], which extensively intersects and combines bibliography, intelligence, mathematics, and statistics, and can reveal the internal structure and trends of specific research directions or specific journals [18]; therefore, it is applied to many specific fields [19]. VOSviewer [20] is a highly used visualization tool in bibliometrics for investigating the current status and development trends, presenting cocitation networks and coauthors, and revealing the structure of a picture research field [21]. Therefore, it is necessary to use bibliometrics to analyze in depth the application of GDM methods in Shipping Industry 4.0, which can help scholars in having a comprehensive understanding of this field and obtaining new research ideas.

The innovations and contributions of this article are the following four points: (1) The existing literature does not combine GDM and Shipping industry 4.0. This article focuses on the application of GDM in Shipping Industry 4.0, which fills the gap in this field. (2) This paper uses bibliometric methods to analyze the retrieved literature that can reflect the current status of research in the field and indicate future research directions. (3) We present a comprehensive overview of the GDM approach as implemented in the shipping industry. The whole process of GDM is reviewed and analyzed in detail, including opinion/preference representation, consensus measure, feedback mechanism, and the selection of alternatives. (4) The article further reviews the specific application scenarios of the GDM approach in Shipping Industry 4.0. This includes the application areas of ship safety risk control and sustainability. The paper concludes with a summary of the relevant lessons learned and suggests possible future research directions.

Figure 1 shows the overall analytical process for this study. The main structure of this paper is as follows: Section 2 describes how the screened papers were analyzed using the bibliometric approach. In Section 3, we present the review of the GDM process from four aspects. In Section 4, specific application scenarios of GDM methods in Shipping Industry 4.0 are discussed. Section 5 presents possible future directions and recommendations. Section 6 concludes the paper.

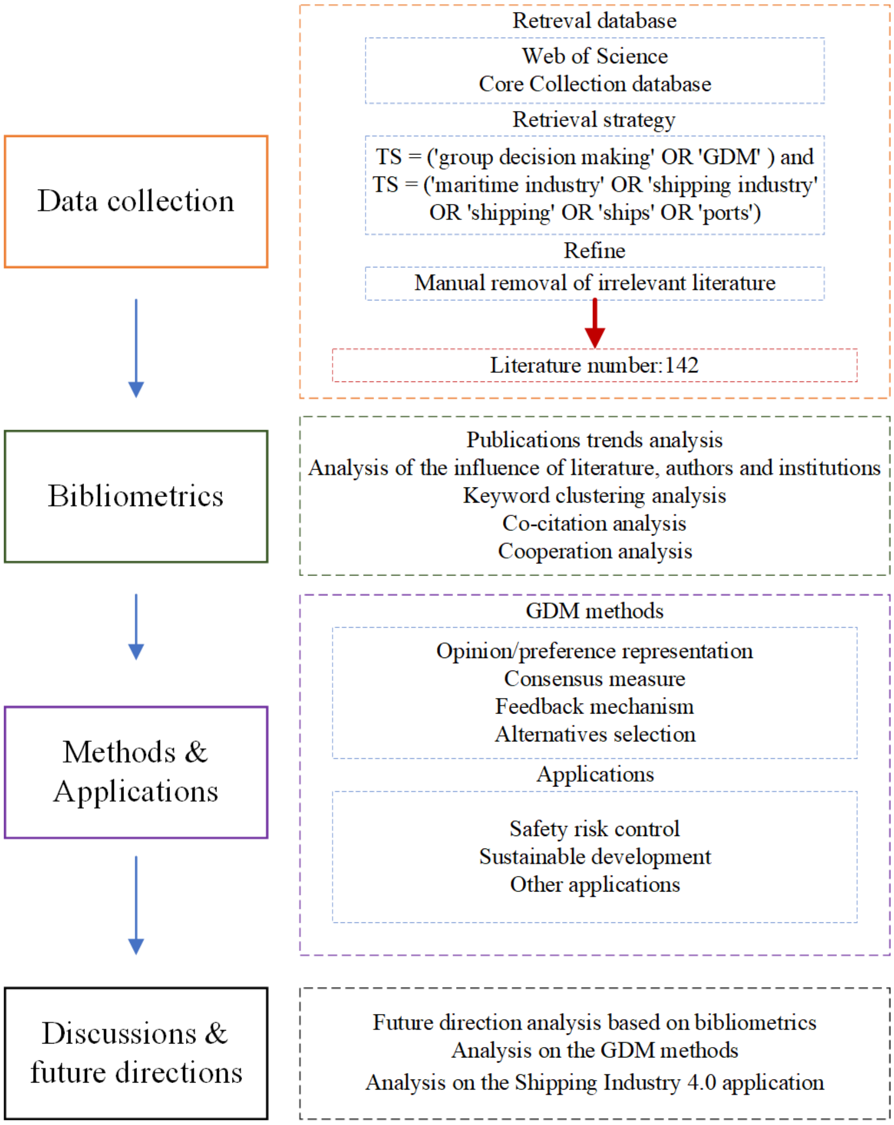

Figure 1. The analytical procedure of this paper.

2. Bibliometrics

The data source for this paper is the Web of Science (WoS) database, where an advanced search formula was used to retrieve studies related to GDM and Shipping Industry 4.0. The specific search formula was: TS = ("group decision making" OR "GDM") and TS = ("maritime industry" OR "shipping industry" OR "shipping" OR "ships" OR "ports") ("TS" was the subject), with no time limit for the search. A total of 263 papers published before the search date (25 July 2022) were selected. Advanced WoS search uses a subject search method that matches the title, keywords, or abstract of a paper with the search terms. Therefore, the matched papers may only mention the keywords in the search formula, but the actual content may not be relevant to the desired papers. In view of this, 142 relevant papers were eventually identified through manual screening. Bibliometric analysis is an effective method to examine the patterns of the published literature in order to illustrate the history and current status of a field. As shown in Table 1, there are a number of scholars who combined bibliometric methods with a number of fields, such as computing [22,23], medicine [24,25], decision science [26], and tourism [27]. The methods used in these studies were instructive for this paper. In this section, we used bibliometric software VOSviewer to visualize and analyze the current status of the application of GDM methods in Shipping Industry 4.0, visually illustrate the development of this field, and suggest possible future trends.

Table 1. The literature on bibliometrics and its application areas.

Authors	Article Title	Bibliometric Tools	Application Areas
Orduña-Malea, E., & Costas, R.	Link-based approach to study scientific software usage: the case of VOSviewer [22]	VOSviewer	Computing
Di Vaio, A., Hassan, R., & Alavoine, C.	Data intelligence and analytics: A bibliometric analysis of human–Artificial intelligence in public sector decision-making effectiveness [23]	VOSviewer	Computing
Lazzari, C., McAleer, S., & Rabottini, M.	The assessment of interprofessional practice in mental health nursing with ethnographic observation and social network analysis: a confirmatory and bibliometric network study using VOSviewer [24]	VOSviewer	Medicine
Huang, T., Zhong, W., Lu, C., Zhang, C., Deng, Z., Zhou, R., Zhao, Z., & Luo, X	Visualized Analysis of Global Studies on Cervical Spondylosis Surgery: A Bibliometric Study Based on Web of Science Database and VOSviewer [25]	VOSviewer	Medicine
Wang, X., Xu, Z., Su, S. F., & Zhou, W.	A comprehensive bibliometric analysis of uncertain group decision making from 1980 to 2019 [26]	VOSviewer	Decision science
Guan, H., & Huang, T.	Rural tourism experience research: a bibliometric visualization review (1996–2021) [27]	VOSviewer & Citespace	Tourism

2.1. Publication Trend Analysis

Using a line graph to analyze the year of publication of the retrieved literature gives a direct view of the trend in the development of the field. When a field is first developed, the number of published studies is relatively small due to the lack of theory and technology, and only a few authors are involved in the research. However, as a field is gradually develops, more authors, institutions, and countries begin to research and collaborate, and the number of published studies gradually increases. As shown in Figure 2, the first study in the field was published in [28]; up till 2014, the number of publications per year in the field was relatively small, and the trend was steady, as part of the early stage of the development of the field. From 2014 onwards, there has been a gradual increase in the published literature, with 29 publications in 2021 and 15 publications in 2022 by 25 July, showing a rapid development in the application of GDM methods in Shipping Industry 4.0. The growth of the literature during this period can be explained by the growing recognition of GDM as a method of decision science, and the fact that the shipping industry developed better during this period, and more scholars are using the GDM method to study the development of the shipping industry. Shipping occupies an extremely important position in international trade due to its low costs and high volumes. The development of Shipping Industry 4.0 can improve the ability of shipping-related enterprises to reflect the market, reduce the operating costs of each link in the shipping industry chain, and accelerate the development of the shipping industry. GDM, as a method for identifying uncertainty and inferring optimal decisions, can be applied to Shipping Industry 4.0 to better develop the shipping industry. Therefore, under globalization, an increasing number of countries and governments are paying more attention to this field. We, therefore, infer that the number of papers in this field will continue to grow in the coming years.

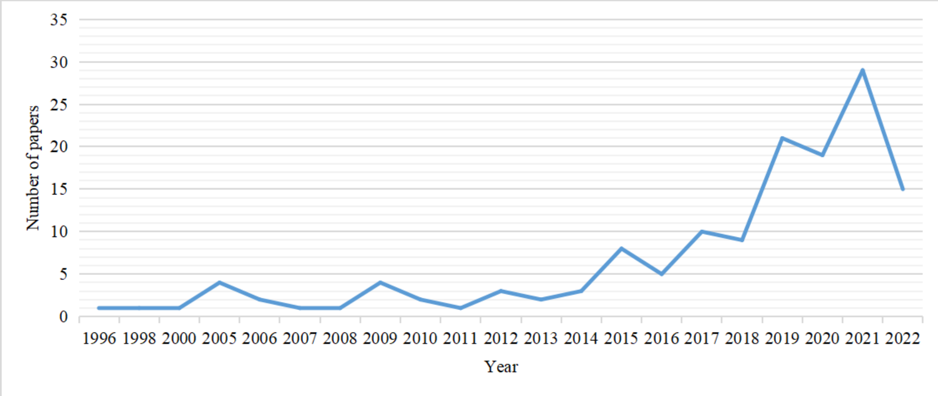

Figure 2. Publication trends of the literature (on 25 July 2022).

2.2. Analysis of the influence of the literature, authors, and institutions

New scholars to a field first study the literature published by authoritative authors and institutions in order to obtain the most accurate and reliable information to help them in deepening their understanding of the field. Therefore, we examined the most cited studies, the most productive authors, and institutions of the field to analyze the most important and authoritative parts of the literature, authors, and institutions in the application of GDM methods in Shipping Industry 4.0. Table 2 shows the 10 most cited studies, 7 with authors from Oxford, 2 with authors from Amsterdam, and 1 with authors from Catonsville. The earliest of these 10 studies were published in 2005 [29], and 6 were published after 2010, which indicates that the development of the field is relatively young, and some of the papers published in recent years are of high quality. The first five of these articles regarded the following: Wang et al. [29] proposed an interval evidence reasoning (ER) method that could handle interval confidence and interval data, and applied it to a cargo ship selection problem. Bulut et al. [30] developed a generic version of the traditional fuzzy hierarchical analysis method (FAHP) and applied it to a shipping asset management (SAM) problem in the dry bulk shipping market problem. Celik et al. [31] proposed a hybrid approach using fuzzy axiomatic design (FAD) and fuzzy techniques in order to manage strategic decisions for container ports with incomplete information. Dulebenets [32] proposed a multiobjective mixed-integer nonlinear optimization model extending a cooperative agreement between liner carriers and maritime container terminal operators. Wu et al. [33] combined ER with the technique for order preference by similarity to ideal solution (TOPSIS) to deal with commanding fewer ships. The remaining five papers mainly examined the shipyard berth facility assessment [34], the optimization of container yard resources [35], ship–bridge collision warnings [36], the selection of ballast water treatment systems for ships [37], and ship selection [38]. Table 3 shows the 10 authors with the most publications, with Soares CG having the most publications, followed by Wu and Yan. Table 4 shows the 10 institutions with the most publications, with Wuhan University of technology publishing 11 papers, followed by Instituto Superior Tecnico and Universidade de Lisboa, which published 8 articles. These author-to-author and institution-to-institution collaborations could be deepened, and new scholars and institutions to the field could also seek to collaborate with these authors and institutions, which would further contribute to the development of the field.

Table 2. Top ten most cited papers

Authors	Article Title	Publication Year	Times Cited	Publisher City
Wang, YM., Yang, JB., Xu, DL., & Chin, KS.	The evidential reasoning approach for multiple attribute decision analysis using interval belief degrees [29]	2006	238	Amsterdam
Bulut, E., Duru, O., Keçeci, T., & Yoshida, S.	Use of consistency index, expert prioritization and direct numerical inputs for generic fuzzy-AHP modeling: A process model for shipping asset management [30]	2012	84	Oxford
Celik, M., Cebi, S., Kahraman, C., & Er, ID.	Application of axiomatic design and TOPSIS methodologies under fuzzy environment for proposing competitive strategies on Turkish container ports in maritime transportation network [31]	2009	79	Oxford
Dulebenets, MA.	A comprehensive multi-objective optimization model for the vessel scheduling problem in liner shipping [32]	2018	78	Amsterdam
Wu, B., Zong, LK., Yan, XP., & Soares, CG.	Incorporating evidential reasoning and TOPSIS into group decision-making under uncertainty for handling ship without command [33]	2018	77	Oxford
Celik, M., Kahraman, C., Cebi, S., & Er, ID.	Fuzzy axiomatic design-based performance evaluation model for docking facilities in shipbuilding industry: The case of Turkish shipyards [34]	2009	74	Oxford
Murty, KG., Wan, YW., Liu, JY., Tseng, MM., Leung, E., Lai, KK., & Chiu, HWC.	Hongkong International Terminals gains elastic capacity using a data-intensive decision-support system [35]	2005	72	Catonsville
Wu, B., Yip, TL., Yan, XP., & Soares, CG.	Fuzzy logic based approach for ship-bridge collision alert system [36]	2019	67	Oxford
Karahalios, H.	The application of the AHP-TOPSIS for evaluating ballast water treatment systems by ship operators [37]	2017	66	Oxford
Yang, ZL., Bonsall, S., & Wang, J.	Approximate TOPSIS for vessel selection under uncertain environment [38]	2017	53	Oxford

Table 3. Top 10 authors with the most publications.

Authors	Number of Papers	Percentage Share
Soares C.G.	8	5.63%
Wu B.	6	4.23%
Yan X.P.	6	4.23%
Demirel H.	5	3.52%
Wang Y.	4	2.82%
Wang Y.J.	4	2.82%
Yang Z.L.	4	2.82%
Yip T.L.	4	2.82%
Alarcin F.	3	2.11%
Balin A.	3	2.11%

Table 4. Top 10 institutions with the most publications.

Affiliations	Number of Papers	Percentage Share
Wuhan University of Technology	11	7.75%
Instituto Superior Tecnico	8	5.63%
Universidade de Lisboa	8	5.63%
Istanbul Technical University	7	4.93%
Chalmers University of Technology	6	4.23%
Hong Kong Polytechnic University	6	4.23%
Dalian Maritime University	5	3.52%
Shanghai Maritime University	5	3.52%
Yildiz Technical University	5	3.52%

2.3. Keyword Co-Occurrence

Keywords are a highly condensed version of the content of an article, and through keyword analysis, we can quickly understand the research hot spots in a particular field. Figure 3 shows the keyword co-occurrence of the retrieved papers involving a total of 1021 keywords. The circles and labels form an element, and the color of the element represents the cluster to which it belongs, with different clusters represented by different colors. The clusters in green, purple, and red were mainly specific to the different segments of the shipping industry, such as "logistics", "supply chain management", "maritime safety", and "accidents". The yellow and blue clusters were mainly decision-making methods, e.g., "fuzzy TOPSIS" and "AHP". The larger the circle is, the more frequently a keyword is used. The circles for decision-making-related keywords such as "decision making", "fuzzy", "TOPSIS", and "AHP" are larger than those for other categories. Keywords related to the shipping industry, such as "risk assessment", "logistics", and "management", also appear more frequently. From this, some popular research directions can be summarized. The main research areas include supply-chain management [12,39–43] and maritime security [44–47]. The main research methods include fuzzy set theory [44,45,47,48], TOPSIS [11,49,50], and AHP [51–53]. This represents the core content of the field. In the future, scholars could focus on high-frequency keywords in order to follow the trend of the times or innovate according to low-frequency keywords. In addition, keywords such as decision support systems and consensus are relatively independent, indicating that there is currently little research on these issues.

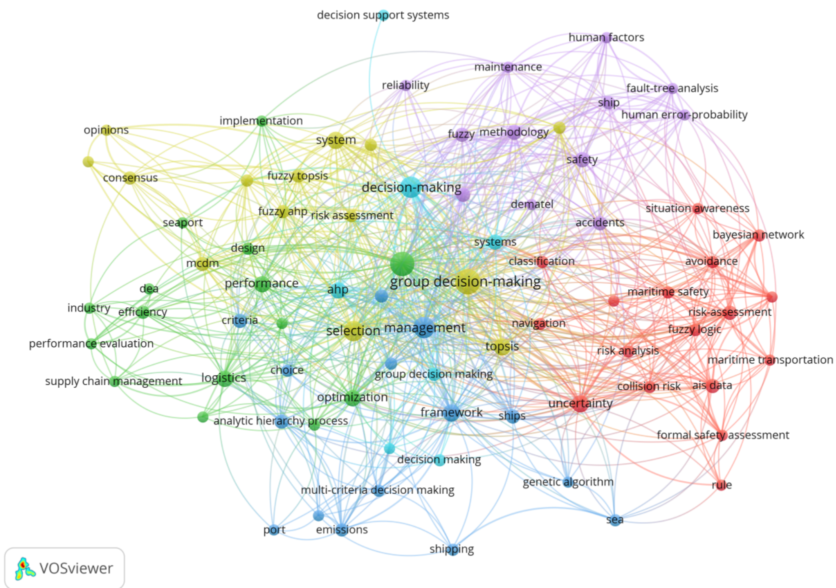

Figure 3. Keyword co-occurrence.

2.4. Cocitation Analysis

Cocitation analysis measures the similarity between documents via the number of times two documents are cited together. The larger the node is, the higher the importance of the author, the literature, and the journal is. Figure 4 shows the cocitation analysis between authors. The three authors with the strongest links to other authors were Wu (total link strength = 1079), Akyuz (total link strength = 595), and Yang (total link strength = 550). Figure 5 shows the cocitation analysis among the studies; the three strongest links to other studies were with Wu [54] (total link strength =106), Wu [33] (total link strength = 96), and Wu [55] (total link strength = 95). Figure 6 shows the analysis of cocitations between journals in the literature. The three journals with the strongest links to other journals were Safety Science (total link strength = 6122), Ocean Engineering (total link strength = 6074), and Reliability Engineering & System Safety (total link strength = 5435). Through cocitation analysis, the most valued and recognized authors, studies, and journals in the field can be analyzed, which is beneficial for other scholars to learn about the field, focus on these valued journals and try to publish their subsequent articles in these journals.

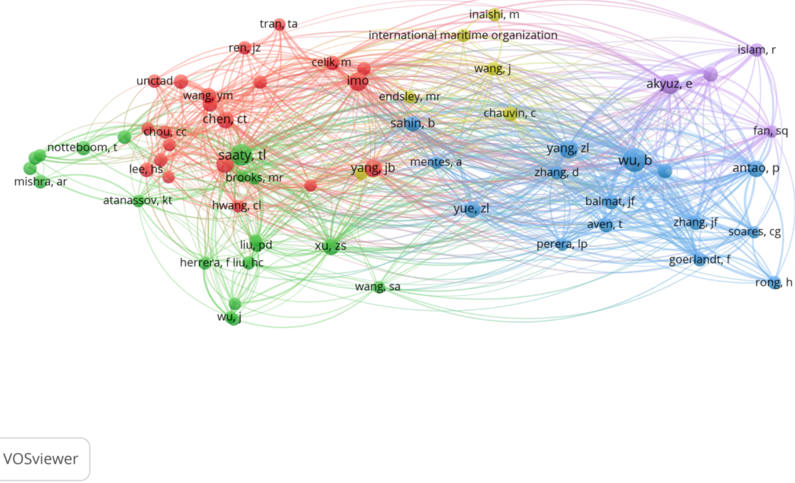

Figure 4. Cocitation analysis—authors.

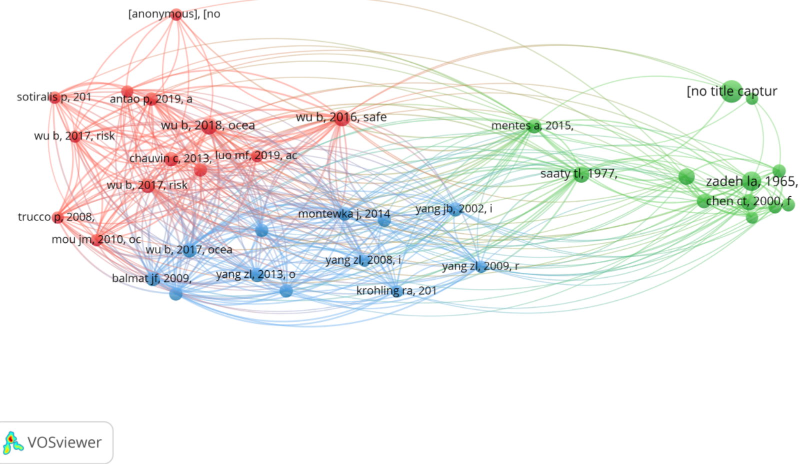

Figure 5. Cocitation analysis—references.

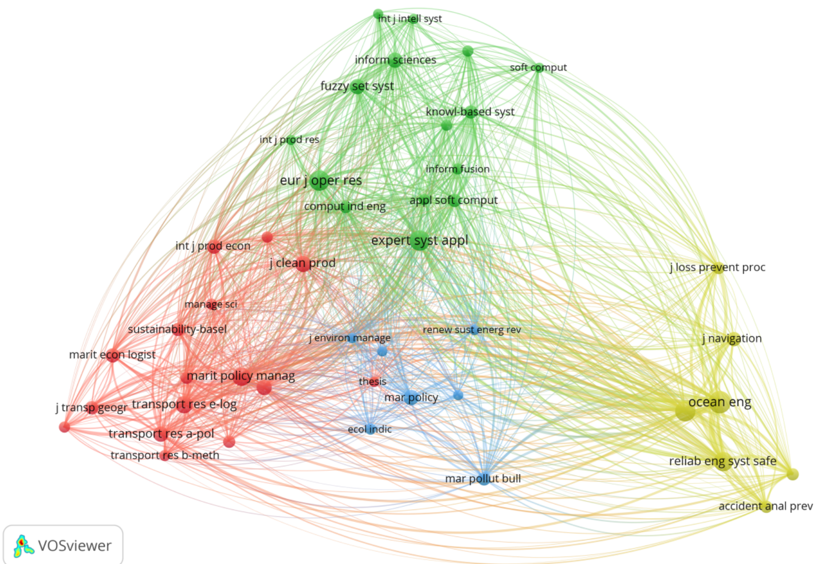

Figure 6. Cocitation analysis—sources.

2.5. Cooperation Analysis

A total of 453 authors, 229 institutions, and 44 countries were published in the field of group decision making and Shipping Industry 4.0, but there are only 142 publications in the field, which implies that there is a good number of collaborative studies between authors, institutions, and countries, and that the development of the field is receiving wider attention. Collaboration between authors, institutions, and countries can contribute to the development of theories in the field, so it is necessary to study these collaborative relationships. Figure 7 shows the collaboration between authors, with differently colored circles representing seven different categories. The size of the nodes indicates the number of publications: the larger the node is, the more studies were published collaboratively. The figure shows more collaborations between authors such as Yan and Wu, and other authors. Figure 8 shows collaborations between organizations that were divided into six categories. The figure shows fewer chains of collaboration between organizations, suggesting that most institutional publications were conducted independently, and that research in this area has not yet developed more centralized collaboration between institutions. A small number of institutions, such as Shanghai Maritime University, Dalian Maritime University, Wuhan University Technol, and Hong Kong Polytech University, collaborate with other institutions. There is a need for greater cooperation and the sharing of resources between institutions in order to better develop the field. Figure 9 shows the collaboration between countries, which is divided into 9 categories. China, the United Kingdom, Japan, the USA, and other countries have collaborated. The analysis of collaborations shows the authors, studies, and institutions that are currently collaborating. If scholars from different institutions wish to study at other institutions, priority can be given to collaborating institutions, and there may be more opportunities to study.

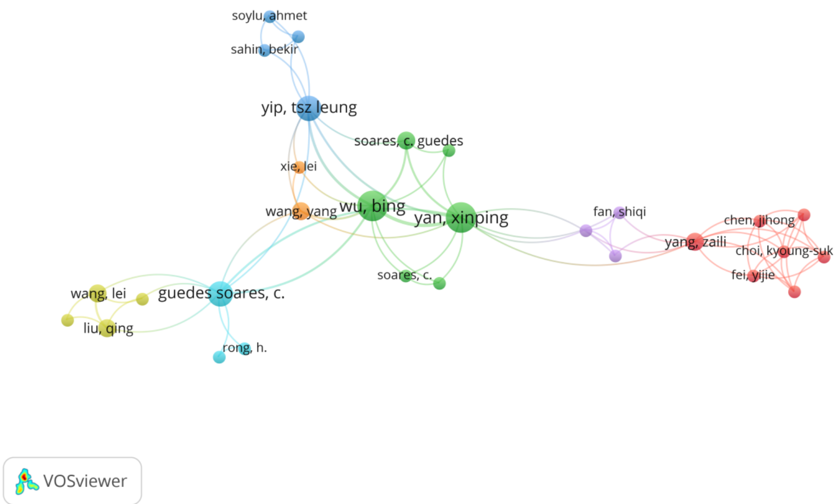

Figure 7. Cooperation between authors.

Figure 8. Interorganizational cooperation.

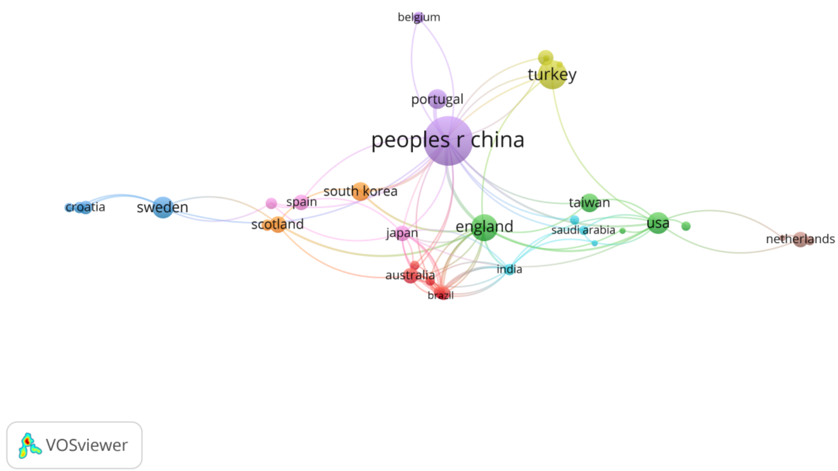

Figure 9. International cooperation.

3. GDM Implemented in Shipping Industry 4.0

This section provides an overview of the literature in terms of the specific procedures and steps of GDM. In the classical GDM model, there are a set of experts and a set of alternatives, and experts need to express their opinions or preferences about the alternatives. If individual opinions do not reach a consensus, a consensus reaching process (CRP) needs to be used to help the group in reaching consensus. After the experts reach a consensus on the alternatives, a specific method is used to rank the alternatives from worst to best and obtain an optimal consensus solution. GDM consists of a CRP and a selection process [56], where CRP includes individual opinion/preference expression, consensus measures, and a feedback mechanism. For convenience, in subsequent expressions, let $D = \{d_1, d_2, \cdots, d_m\}$ and $X = \{x_1, x_2, \cdots, x_n\}$ denote the set of decision makers (DMs) and the set of alternatives, respectively, where $m, n \geq 2$. These four components of the GDM, applied to Shipping Industry 4.0, are outlined in Sections 3.1–3.4 below.

3.1. Opinion/Preference Representation

Opinion/preference representation in GDM refers to DMs expressing their preferences or opinions on alternatives, which can be aggregated to obtain the final collective solution. Considering differences between DMs and the complexity of decision-making problems, many mainstream preference representation structures have been proposed to represent the DMs' opinions/ preferences. Commonly used expression structures in GDM include reciprocal preference relation (RPR), the 2-tuple linguistic model, and fuzzy sets. The following section is a summary of these forms.

3.1.1. Reciprocal Preference Relation

RPR is one of the most common methods of expressing decision makers' pairwise comparison of alternatives. For ease of definition, let P be a fuzzy binary relation for X that has an affiliation function of μ_P, where $\mu_P(x_i, x_j) = P_{ij} \in [0, 1]$ represents the preference degree on the alternative x_i over x_j. If P_{ij} is larger, this means that DMs have a higher strength of preference for x_i relative to x_j. Thus, for d_m, $P_{ij}^m \in [0, 0.5)$ means that x_j is preferred over x_i, $P_{ij}^m = 0.5$ means d_m have the same preference for x_i and x_j, and $P_{ij}^m \in (0.5, 1]$ means that x_j is preferred over x_i.

3.1.2. Two-Tuple Linguistic Model

As information may not be quantifiable or may be costly to quantify, experts may use approximations to describe preferences. An example is the use of linguistic terms to describe values rather than precise numbers. Linguistic terms are words or sentences in a natural or artificial language. For example, words rather than numbers are used to express weight, i.e., very light, light, average, heavy, and very heavy rather than 40, 50, 60, 70, 80, respectively. Linguistic terms have a wide range of applications [30,57–60]. For example, Ardebili et al. [61] used the terms "worst", "worse", "fair", "good ", "best", and other linguistic terms to describe the condition of a ship.

The 2-tuple linguistic model was proposed by Herrera and Martínez [62] to represent linguistic information with two values. The 2-tuple linguistic model can improve the accuracy of linguistic computation after the retranslation step, which consists of a linguistic term $S = \{S_0, S_1, \cdots, S_g\}$ and a numerical value $\propto$ representing the symbolic translation. The linguistic 2-tuple $(S_i, \propto)$ defines a set of transformation functions between numeric values and linguistic 2-tuples. The basic setup of the model is shown below.

$$\begin{gathered} \beta \in [0, g] \\ i = \text{round}(\beta) \in \{0, 1, \cdots, g\} \\ \propto = \beta - i \in [-0.5, 0.5) \end{gathered}$$

where β is a value representing the result of a symbolic aggregation operation of terms in S, and round is the usual round operation.

The advantage of the 2-tuple linguistic model is that the representation of the model remains continuous within its domain, whereas in other traditional linguistic models, it is considered to be discrete [63,64]. Two-tuple linguistic models are used in many applications in the field of decision making: electrical engineering [65], clothing design [66], and corporate performance management [67]. With the application of the 2-tuple linguistic model, optimization models based on these models [68–72] were also extensively studied by scholars.

3.1.3. Fuzzy Sets

When using the GDM method to solve shipping problems, scholars often use fuzzy sets to transform the opinions of experts. Fuzzy sets can deal with uncertainties arising from imprecision and vagueness, and allow for people to express their opinions flexibly. Fuzzy set theory (FST) was first proposed by Zadeh [73]. Fuzzy sets are widely used in solving shipping problems with the GDM method. Each fuzzy set form has different advantages, and scholars can flexibly choose various approaches when solving shipping problems. For example, Ren and Liang [74] applied the fuzzy set concept to logarithmic least squares and TOPSIS to develop a fuzzy group multicriteria decision-making method for ranking alternative marine fuels. Yang and Wang [38] combined fuzzy sets and confidence levels to propose a new approximate TOPSIS method to deal with the development of ship selection models in uncertain environments. Ahn and Kurt [75] used nine fuzzy sets in combination with positive and negative CPC scores to identify human errors that occur during offshore operations.

3.2. Consensus Measure

For any GDM problem, there may exist disagreement or even conflict among DMs due to, for example, differences in their knowledge base and level of awareness. For this, the consensus measure process is necessary to calculate the level of consensus among DMs, so as to obtain the final consensus result. There are usually two types of consensus measures [76]: The first one is a distance measure between individual preferences and group preferences. Herrera et al. [77] first used linguistic distance, which assesses the distance between each expert's linguistic preference relationship and collective opinion. Ben-Arieh et al. [78] investigated the problem of aggregated linguistic preferences while considering the importance and weight of individual preferences. The Delphi method, a traditional GDM method, also uses this rule [76,79]. The moderator collects individual opinions as group opinions and subsequently encourages DMs who hold opinions that are far away from the group opinion to modify their individual opinions, eventually reaching a higher level of group consensus. The second type is to calculate the similarity between individual preferences. Liao et al. [80] defined an alpha-cut-based method to calculate the similarity between different hesitant fuzzy language assessments. Ma et al. [81] proposed an ordered consistency measure with objective thresholds on the basis of preference ranking. Dong et al. [82] proposed a double-hesitant fuzzy soft-number-based consensus measure method and applied it to supplier selection.

However, in general, consensus means that DMs are in complete agreement [83], which is a situation that is difficult to achieve; hence, the introduction of the concept of soft consensus is necessary [84]. That is, the consensus threshold can be specified to be between 0 and 1. Moreover, some scholars separately identify the level of consensus among DMs, alternatives, and preference elements [85].

3.3. Feedback Mechanism

There are always some disagreements or nonconsensus among DMs, and they must be reduced to an acceptable level or eliminated in order to obtain a consensus-based final solution. Feedback mechanisms can provide modifications and guide DMs to adjust their opinions to improve the group's consensus until their level of consensus is greater than or equal to a predetermined consensus threshold. The general feedback mechanism is based on the following two rules.

(1) Identification rule and direction rule (IR–DR). The IR is used to identify DMs, alternatives, and preference elements with poor levels of consensus. Let $CL(d_k)$, $CL(x_i)$, and $CL(v_i)$ denote the level of consensus among DMs, alternatives, and elements, respectively; α is the predefined consensus threshold, and the IR can be expressed as follows:

   (i) Identify DMs with poor levels of consensus: $ID = \{d_k \in D \mid CL(d_k) < \alpha\}$.
   (ii) Identify alternatives with poor levels of consensus: $IX = \{x_i \in X \mid CL(x_i) < \alpha\}$.
   (iii) Identify elements with poor levels of consensus: $IE = \{v_i \in \mathrm{V} \mid CL(v_i) < \alpha\}$.

   After the nonconsensus DMs, alternatives, and preference elements are identified, they are adjusted using the directions provided by DR. For example, Wu et al. [86] devised a local feedback strategy to guide the CRP consisting of four identification rules and two direction rules. Zha et al. [87] considered the willingness of experts to adjust their opinions for which a limited confidence feedback mechanism was proposed to divide DMs into groups and provide acceptable advice to the groups. Using the IR–DR rule to adjust the opinions of adjustment experts is usually time- and resource-intensive, so many academics choose the second rule.

(2) Optimization-based consensus rule (OCR). The OCR is primarily used to minimize the distance or cost before and after the adjustment of DMs [88,89], decision options, and preference elements [90]. The use of OCR allows for as much as possible of the original preference information of DMs to be retained. For example, Ji et al. [91] used a combination of subgroup clustering and a feedback mechanism based on minimal variance weights to determine the online response assessment satisfaction of peer-to-peer (P2P) accommodation users in a large group of decision makers. Cao et al. [85] considered the consensus state of the experts and proposed a personalized feedback mechanism on the basis of a maximal harmony model. Gai et al. [92] developed a minimal adjustment bidirectional feedback model considering cohesion applied to the blockchain platform selection problem in supply chains. Wu et al. [93] proposed a dual personalized feedback mechanism that could generate suggestions by weighting the average of personalized group opinions, achieving a balance between group consensus and individual personality.

3.4. Selection of Alternatives

Once consensus is reached through the feedback mechanism, alternatives can be ranked (from best to worst) and selected. Different selection methods are used for different preference representations and consensus measures. Some traditional ranking methods, such as TOPSIS, BWM, and AHP, are mainly used to solve shipping problems. In this section, we describe these methods.

3.4.1. TOPSIS

For the classical MCDM technique, TOPSIS is widely used in various decision-making areas. The main idea of TOPSIS is to calculate how close an alternative is to the hypothetical ideal positive solution and to the hypothetical ideal negative solution. When an alternative is closer to the ideal positive solution and farther away from the ideal negative solution, it is ranked higher, and the highest-ranking alternative is the best to be chosen by the decision maker. The traditional TOPSIS method is widely used in the shipping industry [33,54,60,94]. Optimization based on TOPSIS has also received attention from scholars. Karahalios et al. [37] combined hierarchical analysis with TOPSIS to compare alternatives and improve the final ranking. Ren et al. [74] used the fuzzy TOPSIS method to determine the sustainability indices of various alternative marine fuels. On the basis of sustainability indices, Yang et al. [38] used Chen's fuzzy TOPSIS method to select suitable ships.

3.4.2. Best–Worst Method (BWM)

The best–worst method was first proposed by Rezaei [95] and it allows for consistent results to be obtained with less comparative information. Its core lies in calculating the similarity and difference between the best and worst criteria [96]. That is, after separately identifying the best and worst criteria, they are separately compared with other criteria, and a nonlinear min–max model is used to identify the weights to minimize the maximal absolute difference between the weight ratio and its corresponding comparison. During the development of BWM, scholars used fuzzy sets, triangular fuzzy numbers, and other methods to extend the BWM to deal with cases of imprecise and uncertain information [97]. Scholars also used BWM to address problems in different domains, such as regional distribution network outage loss assessment [95], the selection of emergency medical suppliers [98], supply chain management [99,100], alternative product design evaluation [101], medical waste management [102], and hotel selection [103]. For example, Du et al. [95] used BWM to identify the optimal criterion weights. Huang et al. [101] fused BWM with integrating rough Z-cloud numbers and a multiattributive border approximation area comparison to develop an alternative integrated design assessment model. Liu et al. [102] used BWM and entropy to identify the weights of DMs, and applied them to evaluate the recycling channel of COVID-19 medical waste. Dong et al. [97] proposed a new triangular fuzzy-number-based BWM for multicriteria decision making and validated it with several application examples.

3.4.3. Analytic Hierarchy Process (AHP)

The basic principle of hierarchical analysis is to quantify the experts' preferences and opinions, and compare and choose options using quantitative analysis. The basic steps of AHP are as follows:

(1) A hierarchical model is established in which different preferences are divided into layers from top to bottom according to attributes, with the lower preferences influencing or being subordinate to the upper preferences and being influenced by or dominating the preferences of the lower layers.
(2) Pairwise comparison arrays are constructed using pairwise comparisons. The eigenvectors of each pairwise comparison array are calculated and a consistency test is performed. If the test is passed, the eigenvectors are the weight vectors; if not, the comparison matrix needs to be reconstructed.
(3) The combined weight vector of the lowest level to the target is calculated and tested for consistency, and if the test is passed, the decision can be made according to the results of the combined weight vector.

AHP, as a simple ranking method, was likewise applied by scholars in many fields: supply chain management [104,105], plain irrigation [106], PPP project evaluation [107], machine selection [108], choosing the best maintenance strategy [109], wind energy project evaluation [110], and offshore wind farm siting [111]. For example, Chai and Zhou [104] integrated an interval-valued triangular fuzzy number in AHP, interval-valued triangular fuzzy number in TOPSIS, and cumulative prospect theory to deal with experts' preferences and opinions (AAF).Burak et al. [106] proposed the hybrid HF–AHP–PROMETHEE II method to evaluate and select agricultural irrigation methods. Savkovic et al. [108] applied the AHP method to define a priority vector in order to evaluate alternative parameters to assess and rank different bucket wheel excavators.

4. Application Scenarios of GDM Methods in Shipping Industry 4.0

Shipping has the advantages of high volume and low freight rates; in cross-border trade, companies tend to choose shipping as a means of transport to reduce costs. However, there are two major drawbacks in the shipping industry, namely, the high risk of shipping safety, and the difficulty in making shipping companies sustainable due to the high cost of shipping facilities and other reasons. Scholars have conducted much research on how to address these two drawbacks. This section reviews the application scenarios of GDM methods in Shipping Industry 4.0, which are divided into safety risk control, sustainability development, and other application areas.

4.1. Safety Risk Control

As shown in Table 5, many papers applied GDM methods to control risks in the shipping industry that can be divided into ship-equipment, navigation, and human-factor risk control.

Table 5. Different applications of GDM in Shipping Industry 4.0.

Category	Application	Reference(s)
Safety risk control	Ship equipment risk control	[45,50,57,112–117]
	Navigational risk control	[33,36,46–48,54,58,118–129]
	Human factors risk control	[44,59,75,130–132]
Sustainable development	Port Management	[34,42,133–148]
	Transport Management	[28,32,38,41,60,149–154]
	Energy planning	[49,74,155–158]
	Environmental pollution control	[37,39,94,159–166]
	Corporate Financial Management	[30,167,168]
	Container yard resource optimisation	[35]
Other applications	Ship supply decisions	[169]
	Choice of shipyard	[53]

For example, in ship-equipment risk control, Bashan et al. [113] used the neutrosophic AHP and trapezoidal fuzzy TOPSIS to assess frequently encountered risks in the cabin of a ship. In navigation risk control, Cao et al. [118] used a personalized individual semantic (PIS) model and a consensus building process with bilateral negotiation to assess LNG transport route risks. In human-factor risk control, Fan et al. [59] proposed a method for developing a maritime accident prevention strategy from a human-factor perspective using a multicriteria decision system. From these perspectives, scholars are more interested in risk control related to shipping equipment, probably because shipping equipment is usually more costly, and requires more careful management and maintenance.

4.2. Sustainable Development

In terms of its own and social development, sustainable development is an issue with which every shipping company should be concerned that requires an integrated approach to the control and management of the main aspects of shipping. These included port management [166], transport management, energy planning [170], and corporate financial management. For example, for port management, as a waterway transportation hub, the digitalization level of ports is increasing. Paulauskas et al. [133] ranked 30 ports in the Baltic Sea, North Sea, and Mediterranean regions in terms of digitalization, and the lower-ranked ports could learn from the higher-ranked ports to improve their own digitalization level; Fang et al. [134] proposed a solution for the optimization of water-resource scheduling in ports. For transport management, scholars studied multimodal transport [149,152], ship scheduling [32], ship selection [38,154], and ship traffic design [28]. For energy planning, Hansson et al. [157] assessed alternative marine fuels, and Erto et al. [158] examined ship fuel consumption. For incorporating financial management, Bulut et al. [30] examined the management of shipping assets in the bulk shipping market; Wang and Lee [167], and Wang [168] assessed the financial performance of companies. In addition, Murty et al. [35] focused on the optimization of container yard resources, and given the high convenience of containers and container shipping as one of the main shipping modes, scholars could pay more attention to the issues related to container shipping in the future. Meanwhile, environmental pollution control, as one of the social responsibilities of enterprises, has also received the attention of many scholars, mainly including the selection of green suppliers [39,161], ballast water management on board [37,162], and biological pollution control on board [163].

4.3. Other Applications

In addition to safety and sustainability issues, some scholars have also focused their research on other application areas. For example, Yalcin et al. [169] combined the Delphi technique (DT) and hesitant fuzzy sets (HFSs) to build a decision support system for ship supply. Božičević et al. [53] used the AHP method to determine an optimal dry port location for the Rijeka seaport. In general, scholars have focused on problems that seriously hinder the development of the shipping industry. Normally, the scope of shipping areas that scholars have studied using the GDM methods is relatively narrow, and other application areas could be given more attention in the future.

5. Discussions and Future Directions

Shipping Industry 4.0 and GDM have been hot topics in recent years. It is, thus. necessary to learn from already available research and to explore future research directions. The previous sections presented the innovations and contributions of GDM in Shipping Industry 4.0. In this section, we summarize the learned lessons and discuss future research directions related to GDM in the shipping industry.

5.1. Future Direction Analysis Based on Bibliometrics

Bibliometric analysis led us to summarize the following directions for future research.

(1) Analysis of publication and citation trends showed that sustainable development and the control of risks in ship navigation are currently the focus of most papers, and related issues are receiving academic attention. However, other issues were less studied by academics, and scholars could try to study other related issues that have not been studied or combine these studied issues with other areas to avoid research duplication.
(2) Analysis of the influence of the literature, authors, and institutions revealed that publications from Oxford had more citations, indicating that Oxford scholars have made outstanding contributions to this area of research. The Wuhan University of Technology also had a number of studies in this area. For experienced scholars and institutions, more cooperation can be carried out with researchers from other regions to promote global research and joint development.
(3) According to the analysis of highly cited papers, scholars have focused more on decision-making methods. However, the used decision methods are not sufficiently

innovative, and could be better developed and more deeply integrated with specific applications in the shipping industry.

(4) In keyword co-occurrences, keywords regarding supply chain management, maritime security, fuzzy sets, TOPSIS, and AHP appeared more frequently. In the future, scholars could increase their research on keywords with high frequency. Scholars can also innovate on the basis of low-frequency keywords, such as biolevel models and decision support systems. Scholars can also find new breakthroughs through keyword regrouping.

(5) In cocitation analysis, authors, studies, and journals with high cocitation frequency are more important and contribute prominently to research in this field. Scholars can read the relevant literature in a portfolio manner, focus on journals with high cocitation frequency, and try to publish subsequent articles in these journals.

5.2. Analysis of GDM Methods

On the basis of the review of the results in Section 3, the following points are suggested as future research directions.

(1) While fuzzy sets are widely used in the representation of opinions/preferences in GDM, other methods are less used, and scholars can expand fuzzy sets more. Whichever method of information representation is used, it is also designed to deal with the uncertainty of the environment, of which subsequent researchers also need to be aware. If the decision is time-constrained, experts may be asked to formulate the information in a way that is easy to handle. For example, relevant DMs should follow the same expression format to simplify the steps of processing the format, which can better handle emergencies.

(2) Feedback mechanisms were rarely addressed in existing articles. In general, the level of consensus among all DMs in GDM is usually below the expected consensus threshold due to the different preferences of DMs for different alternatives, but a higher level of consensus can indicate a better decision outcome. When the consensus level of DMs is less than the consensus threshold, a feedback mechanism is applied to identify discordant decision makers and generate suggestions to modify their initial preferences and help them in obtaining satisfactory results. Future research on the feedback mechanism could be added. It is also worth considering how to set a more reasonable consensus threshold.

(3) In the GDM, the reliability of experts involved in the assessment directly affects the validity of the final alternative ranking results, and an attempt could be made to expand the group of experts. Alternatively, deviations in opinion between experts can be compared, and the opinion of experts that deviates too much may be less reliable; consideration can be given to reduce the weight of that expert. In addition, experts' opinions may be influenced by others, so how to ensure the independence of experts' opinions in the GDM process needs to be investigated.

(4) As described in Section 3.4, scholars have mainly used traditional selection methods, and new selection methods could be investigated. Traditional selection methods are more suitable for cases with small data volumes. With the development of Shipping Industry 4.0 and the increased demand for processing large data volumes, this aspect is also worth investigating.

5.3. Analysis of Shipping Industry 4.0 Applications

For applications of the GDM method in Shipping Industry 4.0, we summarize the following recommendations.

(1) The GDM method can provide a reasonable solution for the assessment and control of safety risks in Shipping Industry 4.0, which has been less of a focus in existing research.For example, the risk assessment of liquefied natural gas (LNG) transportation routes has become a hot topic in recent years. Practically, the risk assessment of LNG transportation routes is a really complicated issue that involves ship-navigation,

meteorological, oceanic-condition, environmental, legal, political, and many other fields [118]. In the existing literature, there is less research on human-factor risk control in the shipping industry. However, given the unique operating conditions of the shipping industry, where crews are exposed to many hazardous situations, a proper estimation of human error can assist in the implementation of emergency training on ships and reduce crew risk. Thus, a GDM process involving multiple professional departments is essential for obtaining a reliable risk evaluation result. In addition, the CRP of GDM can effectively reduce disputes about risk assessment among departments and improve the agreement on the final risk evaluation results.

(2) For the sustainable development of Shipping Industry 4.0, such as the selection of materials for ship construction, ballast water discharge, the selection of marine fuels, the assessment of ship environmental pollution, and the governance of ship carbon emissions, GDM can also be applied. Replacing heavy fuel oil (HFO) with alternative green energy is a promising way to reduce shipping emissions and promote sustainable shipping development. Promoting the application of alternative fuels in shipping has become an industry consensus that promotes profound changes in the international shipping industry, and profoundly impacts upstream- and downstream-related industries in shipping. However, the application of alternative fuels in shipping involves many uncertainties, such as fuel supply, ship financing, technological development, and standard setting. Generally, it is difficult to select the best alternative marine fuel, and environmental, economic, technological, and social factors need to be considered. In this case, multicriteria GDM methods can be used to determine the sustainability order of alternatives and rank the marine fuels.

(3) In recent years, the cruise industry has flourished to become one of the most rapidly developing branches of the shipping industry. Some scholars have investigated cruise ships from different perspectives, but few researchers have paid attention to the rating of cruise ships and cruise routes. The evaluation and rating of cruise ships can also be regarded to be a GDM problem that requires the combination of subjective and objective data to obtain the final rating results of cruise ships. Considering that disagreement among decision makers may emerge, an interaction-based feedback mechanism can be used to improve the consensus level of the group and obtain a satisfactory rating result.

(4) With the development of the Internet and social media, online public opinion also more or less impacts the development of the shipping industry, and analyzing the impact of public opinion on the shipping market is an important research direction. For example, the Suez Canal blockage (SCB) event in 2021 attracted great public attention. This event significantly affected the container market, resulting in an unbalanced distribution of containers. In addition, the blockage affected the global market of oil, gas, and copper. This event aroused wide public concern, and it is meaningful to analyze public attitudes towards SCB and guide public opinion towards a positive trend; the group opinion evolution model can be applied to analyze this process.

6. Conclusions

Compared to air and land transport, water transport is cheaper. Shipping plays an essential role in the development of the global economy. In the Industry 4.0 era, the shipping industry needs to be integrated with new Internet technologies, which not only helps in the integration of new Internet technologies into the real world, but also facilitates the intelligent development of the shipping industry. As a tool for pooling the wisdom of a large number of experts, the application of GDM methods in the shipping industry facilitates more appropriate decisions. In this context, a review of GDM methods in Shipping Industry 4.0 is necessary. First, we analyzed publication trends, the influence of studies, authors, and institutions, keyword co-occurrence, and literature cocitations using bibliometric methods. Then, the whole procedure of the GDM was reviewed and summarized. Next, the specific applications of the GDM methods in Shipping Industry 4.0 were discussed. In the application, we found that existing studies mainly examined safety risk control and sustainable development, which are also main concerns of the shipping industry, but scholars only used a single approach and could use new methods more such as multicriteria decision making. At the same time, the scope of these two issues is broad, but scholars have only studied a small part of them, so it is recommended to expand the scope of research to promote the development of Shipping Industry 4.0. Lastly, the lessons learned from the survey and possible future directions are provided.

There are some limitations in this paper. First, the studied literature in this article only covers a narrow range of applications in the shipping industry, mainly including safety risk control and sustainable development, while other applications were less well-described. In addition, the use of emerging Internet technologies was less well-described and investigated here. In conclusion, researchers may be inspired by this article to research and innovate in this field. In the future, more new Internet technologies will be integrated with GDM and applied to the shipping industry, thus further contributing to the development of Shipping Industry 4.0.

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