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Yui-yip Lau and Tomoya Kawasaki

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About the Editors

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Dr. Yui-yip Lau is a Senior Lecturer in the division of Business and Hospitality Management, College of Professional and Continuing Education, Hong Kong Polytechnic University. He has published more than 325 research papers in international journals and professional magazines, contributed 15 book chapters, 4 books, and presented numerous papers in international conferences. He has collaborated with scholars from more than 20 countries and regions, spread over 5 continents, on research projects. He has also secured over HKD 10 million in research grants. Recently, he has been awarded a Certificate of Appreciation by the Institute of Sea Transport in recognition of his outstanding performance in research, and he has also received the Best Paper Award in international leading conferences. Additionally, he has participated in different consultancy projects with various (inter-)governmental organisations, academic institutions, and industrial associations. In addition, he has been appointed as an Associate at the University of Manitoba, Transport Institute, Winnipeg, Manitoba, Canada, and a Visiting Scholar at East China Normal University. His research interests include cruise, ferry, maritime transport, air transport, impacts of climate change, maritime education and training, transport history, sustainability issues, supply chain management, health logistics, and regional development.

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Preface to "Marine Policy"

Maritime transport contributes over 80% of global trading volumes. As such, marine policy has received a large amount of attention from industrial practitioners, researchers, policymakers, and the local community. In general, marine policy covers a wide-ranging area, including governance, international relations, economics, environmental, and operations, to name but a few. To a certain extent, marine policy fosters the sustainable development of the maritime industry. There has been a wide range of research in different disciplines of marine policy.

The purpose of the book is to publish the most exciting research with respect to the above subjects and to provide a rapid turn-around time regarding reviewing and publishing, and to disseminate articles freely for research, teaching, and reference purposes. Further, the book aims to keep readers up to date with the latest developments and research in maritime affairs.

Yui-yip Lau and Tomoya Kawasaki
Editors

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Editorial

Marine Policy

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The volume of international maritime transport is continuously increasing due to worldwide economic growth and the sophistication of the global supply chain. In 2021, world container flow was recorded as the highest ever, such as 168.2 million TEUs. Vessel size has also continued to increase. As of 2022, the largest container vessel exceeded twenty-four thousand TEUs, which impacts global maritime transport and its management. In addition, port infrastructure planning affects the accommodation of such ultra-large vessels, which is a concern for port practitioners. On the other hand, academicians are also interested in developing new forecasting models and simulators to forecast future cargo demand and flows. Moreover, the environmental issue is becoming important for maritime industries, including maritime transport and port operations. Introducing the idea of a carbon-neutral port forces port authorities and port operators to produce new marine policies. Therefore, marine policy is becoming an increasingly important issue in the maritime industry. To accommodate marine policy for these recent maritime topics, it is important to form appropriate marine policies to achieve sustainable development and further economic growth. Thus, it is important to acquire the necessary knowledge to enable the harmonious and sustainable use of marine resources. Marine policy covers a wide-ranging area, including governance, international relations, economics, environment, and operations. Under this theme, we will explore various theories and methods related to creation and innovation in infrastructure design, multi-modal transportation synchronization, transportation technology, information technology, and management concerning marine policy. We will also discuss approaches to collecting, processing, managing and using any information efficiently and effectively; thus, the research papers published in this Special Issue are expected to contribute to improving the development of appropriate marine policy and value in the face of global challenges in transportation and marine issues. We would like to thank all the authors for their contributions to this Special Issue.

In the modern era, with the rapid development of globalization, maritime transportation has become one of the most important driving forces for global economic development and cultural exchange. Countries around the world are working hard to develop maritime transportation technology and improve port facilities to cope with the rising demand for maritime logistics. Vega-Muñoz et al. [1] observed in the literature that these are related to coastal sustainability and coastal management. Complementing previous studies on coastal zone management and marine territorial planning, coastal systems governance was added as a topic to show its rising importance.

Regarding the international trading situation, Traiyarach and Banjongprasert [2,3] demonstrated the importance of promoting the export of craft products due to the increase in global sales, which is crucial for international commerce. These studies also examined the strategies and competitiveness of exporting craft products by analyzing the results of questionnaires and structural equation modeling (SEM) data.

However, further challenges affect the maritime industry in this dynamic generation.

The sudden outbreak of COVID-19 in late 2019 brought significant losses to the world, and the consequences stunted the development of the maritime industry. Sun and

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Zhang [4]; Zhang and Sun [5] presented how the maritime industry responded to the crisis and simultaneously shouldered its respective responsibility in the world's fight against the pandemic. They demonstrated how this is worth exploring in depth, and how international organizations, International Maritime Organization (IMO) member states, and associate members embarked on maritime management (MM) measures to address dire situations in the context of the COVID-19 pandemic.

Apart from the COVID-19 crisis, safety issues are also considered one of the challenges to the maritime industry. Hsu et al. [6] pointed out a risk assessment of navigation safety for ferries; the proposed approach may provide useful references for related research in the safety management of short-distance passenger ships. At the same time, Miškovi'c et al. [7] discussed the theoretical and practical implications of the results in terms of improving the quality of safety supervision in the maritime industry.

However, global climate changes caused by carbon emissions are considered one of the main issues that affect the maritime industry's development. Li et al. [8] offered valuable insight into the energy conservation and emission reduction in marine fisheries while enhancing the ecological benefits of their carbon sinks and helping to achieve the carbon neutrality target. This can reduce the negative impacts and limitations of Chinese cruises that have unfolded in the Arctic cruise market, as mentioned in the study by Lau et al. [9].

Correspondingly, the difficulties of implementing blockchain (BC) technology in maritime developing countries were raised by Kapidani et al. [10], together with the uncertainties in liner shipping operations and ship schedule recovery in response to the disruptive events mentioned by Elmi et al. [11]. Additionally, Jeon et al. [12] commented that increasing marine accidents due to inappropriate communication between crew members are one of the threats to the shipping industry, and this paper established a need to develop Standard English for engineers in order to reduce the incidents caused by their lack of English skills. More concerns have been pointed out, which require solutions to prevent the regress of development in the shipping industry.

The above studies highlight the importance of management and efficient dilemma response capability in the event of a crisis. As a main hub in the maritime transportation system, ports are vulnerable to events such as terrorist attacks, security accidents, and poor weather. The failure of port nodes to function effectively affects the connectivity and efficiency of the shipping network and impedes trade between countries. Yang and Liu [13] provided a scientific basis for ensuring the structural resilience of the Maritime Silk Road shipping network.

To better manage and maximize the benefits generated by the maritime industry, successful planning is necessary. Saito et al. [14] used graph theory to perform an empirical investigation into the development of international maritime container transport networks, with a primary emphasis on the 1970s. The authors examined the changes in the container shipping networks before and after the reopening of the Suez Canal in 1975, in addition to assessing the changes in overall network architecture over the long term (from the 1970s to the present) and mid-term (in the 1970s). This contributes to accumulating empirical knowledge on the vulnerability analysis of the present and future maritime container shipping networks.

Furthermore, Kawasaki et al. [15] clarified the impact of port developments and an increase in container cargo demand from the source country on maritime network selection from the perspective of shipping lines, by developing a mixed-integer linear programming model to describe vessel deployment, using the example of transshipment via the Colombo port and direct shipment in Indian ports. The article also highlights the importance of maintaining the port as a logistics and transportation hub and details how to increase the demand for cargo.

To conclude, the maritime industry is rapidly developing in a dynamic environment, acting as an important characteristic to boost the trading economy all over the world. At the same time, it also faces many risks and challenges. A comprehensive management system and efficient reaction to external threats is needed to maintain its competitiveness and ensure its smooth operation.

Conflicts of Interest: The author declares no conflict of interest.

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Article

The Influence of Shipboard Safety Factors on Quality of Safety Supervision: Croatian Seafarer's Attitudes

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Abstract: According to the European Maritime Safety Agency (EMSA), 70% of accidents on board were caused by human error, and almost one-fifth of these accidents have been related to inadequate supervision. Therefore, the aim of this study is to investigate which of the safety factors can influence the quality of safety supervision. For this purpose, a questionnaire with 24 statements was distributed to professional seafarers. Two exploratory factor analyses were conducted to identify the underlying factor structure. The first analysis yielded one factor, quality of safety supervision, and the second analysis yielded four factors, namely: safety communication, safety training, safety compliance, and safety rules and procedures. Hierarchical multiple regression analysis was applied to examine the influence of seafarers' demographic characteristics and the four identified factors on the quality of safety supervision. The results revealed the following two statistically significant predictors of safety supervision quality: safety communication and safety training. The theoretical and practical implications of the results in terms of improving the quality of safety supervision in the maritime industry were discussed and compared with results in other industries.

Keywords: maritime industry; safety management; ISM Code; safety supervision; shipboard safety

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1. Introduction

According to Bhatacharya [1], work-related accidents and occupational injuries are challenging areas in any industry, including maritime. According to published data from European Maritime Safety Agency (EMSA), 58% of all reported accidental events between 2011 and 2017 were attributed to human error [2]. Furthermore, 70% of all accidents caused by human error were related to shipboard operations and in 19.6% of cases, inadequate supervision was a decisive factor.

In order to enhance maritime safety, the International Maritime Organization (IMO) has introduced a whole range of regulations and standardized training for seafarers in recent decades. A series of accidents in the 1980s, caused by both human error and management mistakes, led to the development of the International Safety Management Code (ISM) in 1998. One of the main objectives of the ISM Code was to prevent human injuries and fatalities, i.e., to lay the foundation for a new safety culture [3,4]. On the other hand, the Code only provides general guidelines that can be interpreted in different ways, i.e., company-specific according to management's commitment, values, and beliefs [3,5].

The Maritime Labour Convention (MLC) states that national laws, regulations, and other measures must clearly define the responsibilities of all parties to implement and comply with the occupational safety and health (OSH) policy in order to ensure that the shipboard working environment promotes occupational safety and health [6] (p.60). In addition, the company is required to ensure adequate supervision of the employee's work practices [7,8].

The management structure should provide guidance and motivation for safe working practices through their supervisors. In the shipping industry, supervision is based on two different levels of hierarchy: (a) a designated person or persons ashore who have the responsibility and authority to overseesafety aspects and provide adequate resources and shore-based support; and (b) the ship's master who has the responsibility to implement the company's safety and environmental policy and to motivate the crew to carry out that policy [4].

Although shipping companies are required to implement the ISM [4] and MLC (2006) guidelines [7], which elaborate on the duties of supervisors, available statistical data points to the disturbing situation in the maritime industry [2]. Following maritime accidents and incidents, numerous studies have been conducted and human error and management mistakes have been identified as the root cause (e.g., [9,10]). Numerous recommendations are made, but accidents and incidents still occur. The question that still arises is which factors influence onboard safety supervision practices.

The study presented here is based on a quantitative methodological approach with the aim of investigating and determining the quality level of safety supervision, as well as the inherent shipboard safety factors, i.e., their enforcement in real life from the seafarers' point of view. The objectives and requirements stated in the ISM Code were considered along with the results of previous studies to identify factors related to the ship environment. Finally, the influence of the inherent shipboard safety factors and the demographic characteristics of the respondents (age, cumulative sea service time, and company tenure) on the quality of safety supervision in the maritime industry will be investigated.

This paper is organized as follows. Section 2 provides a literature review and theoretical background. The methodological process, including data collection and methods used to achieve the study objectives, is described in Section 3. The results of the study are presented in Section 4 and the significance of the results is discussed in Section 5. The conclusion is presented in Section 6.

2. Theoretical Background

2.1. Safety Climate

The construct of safety climate is well explained in the literature and described as a "sub-component" of safety culture (e.g., [11]). One of the most commonly cited definitions defines safety climate as "shared perceptions with regard to the priority of safety policies, procedures and practices and the extent to which safety compliant or enhancing behavior is supported and rewarded at the workplace" [12] (p. 318). According to Beus et al. [13], safety climate plays a crucial role in workplace safety. However, disputes regarding the dimensions of safety climate are still present [14]. In his early study, Zohar [15] identified eight factors: the importance of safety training, work pace effect on safety, the status of the safety committee, the status of the safety officer, the effect of safe conduct on promotion, risk in the workplace, management attitudes toward safety, and the effect of safe conduct on social status (p. 100). Flin et al. [16] conducted a thematic analysis of the literature and identified the existence of three core dimensions: management, risk, and safety arrangements. Likewise, three additional dimensions were highlighted: work pressure, competence, and procedures. Beus et al. [13] conducted a meta-analysis of safety climate and related injuries and identified six dimensions: management commitment to safety, priority of safety, management safety practices, safety procedures, safety communication, safety reporting, and employee safety involvement (p. 721).

In addition, the results of previous studies indicate a positive relationship between safety climate and safety performance [15,17], safety behavior [11],and shipboard safety [18].

2.2. Shipboard Safety Factors and Safety Supervision

Looking at the shipboard environment, it is clear that the safety climate is influenced by other factors, such as each company's official safety policy, management commitment, and especially the company's own SMS, which is based on the ISM. Among other general requirements, the ISM Code emphasizes the importance of safety communication, safety rules and procedures, safety training, and compliance with safety regulations [4].

Communication is an essential aspect of any organization as it leads to trust between all stakeholders and its importance for positive safety performance has been highlighted [19]. An open and constructive atmosphere must be created where all team members can talk freely about all work-related aspects and work together to solve problems [20]. Vredenburgh [19] studied the impact of safety communication on injury rates and found no significant relationship. Other research has shown that poor communication is a major cause of poor safety performance, productivity, and morale (e.g., [21]).

The IMO has recognized the importance of safety training and has set the requirements accordingly in the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW). In addition to the mandatory requirements that every seafarer must meet, additional measures for specific safety training are also specified. One of the ISM Code provisions states that a "Company should establish and maintain procedures for identifying any training which may be required in support of the SMS and ensure that such training is provided for all personnel concerned" [4] (p. 4). The above requirement is of great importance as ship crews change frequently and new employees do not have sufficient practical knowledge of the company's SMS. Such training should enable each crew member to acquire the necessary knowledge and skills, i.e., to understand the meaning and importance of the safety rules and procedures and thus to react properly in critical and dangerous situations in real life. According to Vinodkumar and Bhasi [22], safety training can predict safety compliance, participation, and motivation. Lu and Yang [23] found a positive relationship between safety training and emergency preparedness, safety compliance, and safety participation.

According to the objectives of the ISM Code, shipping companies should establish safe work practices for ship operations to eliminate significant hazards and work-related risks. To achieve these objectives, companies should provide written rules, procedures, and methods that describe ways to reduce risks. A study by Vinodkumar and Bhasi [22] has shown that there is a positive relationship between safety rules and procedures and safe work practices in high-risk facilities.

The basic requirement for any organization should be to ensure that all employees comply with mandatory safety rules and regulations, i.e., to bring employee behavior in line with safety standards. According to Neal and Griffin [24], the term safety compliance refers to the "core activities that individuals need to carry out to maintain workplace safety" (p.947). According to Puah et al. [25], organizational and fellow worker support is positively related to safety compliance. The results of the study by Heyes et al. [26] show that management safety practices are the best predictors of safety compliance.

The role of supervisors has become the subject of research addressing the issue of organizational safety. The way supervisors behave in the performance of their duties is critical. According to [27], one of a supervisor's responsibilities is to communicate OSH policies and procedures to employees. Due to their direct contact with subordinates and their presence on the worksite, supervisors have a significant influence on safety-related behavior [27,28]. When the supervisor's safe work practices deviate from the company's safety policies and procedures, adverse events may occur [18]. Zohar notes that a consistent supervisor attitude towards safety, especially in "safety vs. efficiency" situations, promotes safety as a priority in the group [28]. Furthermore, it is the supervisor's responsibility to support the safety of his subordinates. In the literature, safety support is defined as "the extent to which supervisors encourage safe working practices among their subordinates" [29] (p. 485). Several studies have shown that greater safety support correlates with fewer workplace injuries and negative outcomes (e.g., [26,29]).

In addition, previous studies investigating the cause of accidents on board ships have pointed to age as a potential risk factor on board, i.e., they have found that a higher risk of accidents is associated with younger seafarers [30,31].

3. Methodology

The methodology used in this study, the analyses performed, and the presentation of results are in accordance with available scientific guidelines and recommendations [32–34].

3.1. Measures

The identification of safety climate measures was based on a review of the scientific literature. For the purposes of this study, the selection of items was based on the provisions of the ISM Code [4] and MLC guidelines [7], as well as the expert opinions of the authors, which together describe the key elements necessary for successful shipboard operations. To ensure validity, items were selected based on questionnaires already used in the maritime industry [35–37] and generic safety climate questionnaires [17,38–40]. A total of 24 items on safety climate were selected from previous studies. The first set of four items contains the main requirements for shipboard safety supervision. In practice, safety supervision tasks are assigned to the ship's captain, safety officer, and department heads, so the phrase 'Ship's management structure' was used.

The second group of 20 items refers to the main objectives stated in the ISM, especially the requirements contained in the chapters: 5. master's responsibility and authority; 6. resources and personnel; 7. shipboard operations; and 8. emergency preparedness. Basically, the above requirements can be expressed as issues related to communication, training, safety compliance, and safety rules and procedures that create a specific onboard environment. Translation of selected items, along with minor modifications, was done by the authors and an English language expert.

3.2. Data Collection

The data used for this study were obtained from a survey conducted on the premises of accredited training institutions in Dubrovnik, Split, Šibenik, and Rijeka (Croatia), where respondents attended STCW courses, from October 2019 to January 2020. Before the questionnaires were distributed, the purpose of the survey was explained to the respondents. To avoid biased participation, the survey was anonymous and confidential. In addition, no incentives were offered to avoid hasty participation. To avoid directing or influencing participants' responses, all statements in the survey were worded as neutrally as possible. The minimum requirement for participation in the survey was that the respondent had completed a tour of duty onboard, regardless of rank.

A five-point Likert scale (1—strongly disagree to 5—strongly agree) was used for all statements. In addition, statements were scattered throughout the questionnaire and a certain number of statements were reverse coded, i.e., higher values indicated higher negative perception of the subject matter. The questionnaire was administered and collected by the authors. A total of 413 questionnaires were collected. An initial review was conducted to discard copies with obvious inconsistencies, i.e., respondents checked all statements as either "1" or "5", or questionnaires contained incomplete responses; 27 copies. Further analysis of the data was conducted to ensure normality and reliability of the data, i.e., to identify possible outliers. In this process, described in Section 3.4, a total of 86 responses were discarded.

3.3. Survey Sample

Background variables of respondents included the following six questions: nationality, age, rank on board, sea time experience, type of vessel they work on, and tenure with the current company. All respondents were of Croatian nationality, $n = 300$. The largest part of the sample consisted of deck officers (64.3%), followed by engineers (24.7%), electro-technical officers (8%), and other crew members (3%). Regarding respondents' age, the largest part-declared age group "26–35" (41.7%), followed by "36–45" (22.7%), "46–55" (16.6%), "18–25" (11.7%), and "56–65" (7.3%). In terms of sea service, the largest part (31.7%) stated ">15" years of sea service, followed by "1–5" years (23%), "6–10" years (21%), "<1" year (13%), and "11–15" years (11.3%). Regarding the vessel type where respondents were engaged, 35.3% reported tankers (all types), 22.7% container vessels, 16.3% passenger vessels, 16% cargo vessels (bulk carrier, general cargo, Ro-Ro), and 9.7% stated other types of vessels. In terms of tenure with the current company, the largest group (45.7%) declared ">4 years" with the company, followed by "<1 year" (23.3%), "2–3 years" (13.3%), "1–2 years" (9%), and the smallest group (8.7%) declared "3–4 years". Considering the respondents' background details, it can be concluded that respondents had enough practical experience to provide qualified answers on the subject matter.

3.4. Method of Data Analysis

All reverse-scored items were reverse coded so that the numerical scoring scale ran in the opposite direction; e.g., responses with a low-value score such as "1 strongly disagree" were transformed into a higher value, "5 strongly agree".

Given the nature of the data collected, factor analysis was chosen among the available multivariate methods. Factor analysis itself offers two main possibilities. For hypothesis testing procedures, confirmatory factor analysis is recommended, the aim of which is to test hypotheses about the structures of the latent variables and their relationships. In cases where exploration of the data is required and the aim of the study is to generalize the results to the population, exploratory factor analysis is recommended. Among the available extraction methods, principal component analysis (PCA) is recommended, given the study objective [33]. The only limitation of the mentioned method is that the results cannot be extrapolated beyond this particular sample, i.e., in this case beyond seafarers of Croatian nationality. Therefore, two exploratory factor analyses (EFA) were performed to reduce the number of variables to a manageable size and to define the underlying factor structure [33]. In order to determine the factor structure, the principal component analysis (PCA) was used as the extraction method. The objectives of PCA are: extracting information from the variables used, compressing their size, simplifying the data description, and analyzing the structure of the observations. During the process, PCA creates new variables called principal components. The first principal component accounted for the largest amount of variability in the data. The second and any other components that were not correlated with each other contributed to the next largest remaining variability whenever possible [34]. To better interpret the factor model obtained, the model was rotated. The rotation method used was varimax rotation, which preserves the original structure while allowing for easier interpretation of the factors [33].

Following EFA, factor scores were calculated for each component obtained. A mean value of the variables used was calculated for each component. The internal consistency (reliability) of the construct, the assigned items, and the summated scales were then assessed using Cronbach's Alpha. Following the EFA, confirmatory factor analysis (CFA) was performed to confirm the un-dimensionality structure of the model, including the convergent validity survey and the discriminant validity inspection. A bivariate correlation analysis (Pearson) was conducted to examine the relationship between all factors in the study. Finally, hierarchical multiple regression analysis was used to explore the influence of independent variables on dependent variables [34]. Prior to the analysis, the assumptions underlying regression analysis were tested, as recommended [33]. All calculations were performed using IBM SPSS and AMOS V26.0.

4. Results

The common method bias was assessed before the EFA's. For this purpose, Hartman's single factor test was applied. According to [41,42], bias is present when the extraction of a single factor results in explaining most of the variance of the variables tested; the threshold is 0.50. The results obtained show that the total variance (38.36%) of all the variables used is below the threshold, therefore the common method variance is acceptable.

4.1. Exploratory Factor Analysis of Safety Supervision Related Variables

Exploratory factor analysis was conducted to examine the factor structure of four safety supervision-related variables. The following analytic criteria were applied: (a) list-wise deletion, (b) Eigen-value higher than 1.0, and (c) cut-off value for factor loadings below 0.5 to ensure practical significance [34].

The statements used are from the Zohar and Luria questionnaire [17]. The wording of the statements used was slightly modified to fit the purpose of the study. Statements used are:

- "The ship's management structure supervises that the assigned operations are performed safely in accordance with the procedures provided",
- "The ship's management structure often checks that all crew members adhere to safety rules and procedures",
- "The ship's management structure requires strict adherence to the procedure even when we are tired or stressed",
- "The ship's management structure supervises the use of protective devices and equipment strictly".

Obtained test results indicated that the data were suitable for factor analysis; Bartlett's test (approx. Chi-square) was 459.559 ($p < 0.001$) and Kaiser-Mayer-Olkin's measure of sampling adequacy was 0.755. The final result yielded one component with an Eigen-value of 2.640, explaining a total of 66% of the variance.

Obtained factors included four items relating to the perceived supervision of assigned jobs and safety procedures adherence. Therefore, it can be referred to as the *quality of safety supervision* (Cronbach's Alpha = 0.820).

4.2. Exploratory Factor Analysis of Shipboard Environment Related Variables

The exploratory factor analysis was carried out to examine the factor structure of 20 shipboard environment-related variables. The same analytical criteria as in the previous analysis were used. Bartlett's test (approx. Chi-square) was 3396.204 ($p < 0.001$) and Kaiser-Mayer-Olkin's measure of sampling adequacy was 0.893 indicating that the data were suitable for factor analyses.

Based on the set criteria, the initial analysis yielded four components and three items were found without loading, i.e., variables failed to load on any component. The analysis was repeated without the mentioned items. The final result yielded four components with an Eigen-value higher than 1, explaining a total of 68.2% of the variance.

Excluded items in the analysis were: "Working with defective equipment is not permitted under any circumstances" [38], "Safety rules and procedures are prepared and available for use" [40], and "Safety rules and procedures contain all important safety information" [40].

All components were checked for reliability using Cronbach's Alpha (>0.70), as recommended [33,34]. Therefore, a four-factor solution was accepted, as presented in Table 1.

Table 1. Exploratory factor analysis of shipboard environment related variables (n = 300).

Statements	F1	F2	F3	F4
Communication between superior and subordinate officers, regarding safety, is good [35]. (M)	0.788			
There is a sense of freedom while communicating with superiors [35].	0.787			
Communication with designated person/s ashore, regarding safety, is good [35].	0.745			
Communication between all crew members, regarding safety, is good [35]. (M)	0.734			
Communication with superior officers, regarding safety, is good [35].	0.723			
Resolving conflict situations on board is at a good level [35].	0.719			
Company provides safety staff with "force" required to perform their job [35].	0.691			
Superior officer always closely explains the work plan and procedures before certain actions (e.g., mooring) [35].	0.574			
I have received the training that is necessary in order to handle critical or dangerous situations [37].		0.872		
I have received the training that is necessary in order to work safely [39].		0.824		
Through training, I got acquainted with all safety rules and procedures [35].		0.814		

Table 1. *Cont.*

Statements	F1	F2	F3	F4
After the start of employment, I was provided with all the necessary theoretical and practical knowledge in order to be able to follow the rules and procedures on board [35].		0.551		
I am able to use the required protective equipment according to the nature of the work [35].			0.868	
According to training sessions, I can actively participate in the workplace hazard elimination [35].			0.723	
I think our (group) duty is to maintain a safe working environment [36].			0.602	
I feel that it is difficult to know which procedures are applicable in practice [36]. (R, M)				0.928
The procedures are difficult to understand or are poorly written [36]. (R)				0.920
Eigenvalues	7.09	1.76	1.48	1.28
Accumulative variance	41.68	52.05	60.73	68.23
Cronbach's Alpha	0.901	0.861	0.716	0.854

M-modified (wording); R-recoded.

Factor 1 included eight items related to the perceived safety and daily communication between all levels of the ship's complement and "ship-to-shore" communication. Therefore, it can be referred to as *safety communication* (Cronbach's Alpha = 0.901).

Factor 2 included four items related to the perceived quality of safety training. Therefore, it can be referred to as *safety training* (Cronbach's Alpha = 0.861).

Factor 3 included three items related to the perceived safety compliance. Therefore, it can be referred to as *safety compliance* (Cronbach's Alpha = 0.716).

Factor 4 included two items related to the perceived quality of safety rules and procedures and their applicability in practice. Therefore, it can be referred to as *safety rules and procedures* (Cronbach's Alpha = 0854).

4.3. Model Fitness, Canvergent and Discriminant Validity

To test the validity and relationship of the identified factors and to verify the model fitness, a confirmatory factor analysis was conducted along with maximum likelihood estimation. The results of the model fit test prove that the model is acceptable; chi-square/DF = 1.644, goodness-of-fit index (GFI) = 0.901, adjusted goodness-of-fit index (AGFI) = 0.875, comparative fit index (CFI) = 0.970, and root mean square error of approximation (RMSA) = 0.051.

The convergent and discriminant validity were tested using the same analysis. For this purpose, the following recommendations were adopted; (a) all standardized factor loadings should be greater than 0.5 (ideally > 0.7), (b) average variance extracted (AVE) should be greater than 0.5 to suggest adequate convergent reliability, (c) composite reliability (CR) should be 0.7 or higher to prove adequate convergent reliability, and (d) square root of AVE should be greater than the inter-construct correlations [34,43].

The standardized factor loadings obtained are well above set minimum value (the lowest was 0.665 and the highest was 0.922) indicating that this requirement is fulfilled. The values of AVE and CR are above set values indicating that the model has satisfactory composite and convergent validity. The discriminant validity was also verified; all square roots of AVE, presented on diagonal, were higher than other inter-construct correlations (Table 2). Thus, it can be concluded that the model has satisfactory convergent and discriminant validity.

Table 2. Inter-construct correlations, convergent, and discriminant validity.

Construct	CR	AV	1	2	3	4	5
1. Compliance	0.714	0.515	**0.718**				
2. Safety rules and procedures	0.854	0.746	0.256	**0.864**			
3. Safety supervision	0.830	0.659	0.590	0.080	**0.812**		
4. Safety training	0.875	0.641	0.536	0.126	0.607	**0.800**	
5. Safety communication	0.905	0.633	0.650	0.182	0.790	0.627	**0.796**

4.4. Pearson Correlation Analysis

Table 3 shows the means, standard deviations, and the correlations between all of the variables included, based on EFA analysis. The perceptions of safety supervision were strongly positively correlated with the perceptions of safety communication ($r = 0.70$, $p < 0.01$) and moderately positively correlated with the perceptions of safety training ($r = 0.56$, $p < 0.01$) and safety compliance ($r = 0.44$, $p < 0.01$). Moderate significant inverse correlations were also found between the perceptions of safety communication and safety training ($r = 0.62$, $p < 0.01$), safety communication, and safety compliance ($r = 0.50$, $p < 0.01$) and between the safety training and safety compliance ($r = 0.46$, $p < 0.01$).

Table 3. Means, standard deviations, and correlations among study variables ($n = 300$).

	M	SD	1.	2.	3.	4.	5.	6.	7.	8.
1. Age	2.66	1.11	-							
2. Sea Service	3.26	1.44	0.79 **	-						
3. Company tenure	3.44	1.66	0.47 **	0.63 **	-					
4. Safety supervision	3.93	0.76	0.13 **	0.16 **	0.01	-				
5. Safety communication	4.06	0.66	0.20 **	0.23 **	0.04	0.70 **	-			
6. Safety training	4.21	0.69	0.11	0.18 **	0.06	0.56 **	0.62 **	-		
7. Safety compliance	4.50	0.52	0.18 **	0.31 **	0.19 **	0.44 **	0.50 **	0.46 **	-	
8. Safety rules and procedures	3.39	1.19	0.11	0.15 **	0.19 **	0.05	0.15**	0.15 *	0.20 **	-

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

4.5. Testing the Assumptions

The assumptions for hierarchical multiple regression analysis were tested before the analysis. The assumptions for linearity, influential cases, homoscedasticity, and residuals were screened using the scatterplots and the plots of standardized predicted values versus standardized residuals. It was concluded that the data were approximately normally distributed. The assumption of independent errors, i.e., whether the values of residuals were independent, was tested using the Durbin-Watson test. The obtained value of 1.887 indicated that residuals were uncorrelated [33]. In order to investigate the problem of possible multicollinearity, the inflation factor (VIF) and tolerance values were examined. According to Field [33], there is no problem with multicollinearity when the tolerance value is above 0.2 and the VIF value is below 10. The minimum tolerance value determined was 0.382 and the maximum VIF value was 2.621, indicating that the assumption was fulfilled. Furthermore, the assumption of no influential cases was tested by calculating Cook's distance; values below 1 had no influence on the model [32]. The maximum value obtained was 0.06, indicating that there are no influential cases.

4.6. Hierarchical Multiple Regression Analysis

Hierarchical multiple regression analysis was used to estimate the influence of independent variables on dependent variables. Independent variables were included in successive steps to explore the influence of respondents' age, sea service, company tenure, perceived communication, safety training, safety compliance, and quality of safety rules and procedures on the quality of safety supervision (Table 4).

Table 4. Hierarchical multiple regression analysis predicting quality of safety supervision (standardized Beta coefficients).

Factors	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
Age	0.127 *	0.001	−0.009	−0.032	−0.011	0.002	0.002
Sea service		0.160	0.270 *	0.051	0.028	0.005	0.004
Company tenure			−0.161 *	−0.038	−0.042	−0.047	−0.035
Communication				0.696 **	0.565 **	0.536 **	0.540 **
Safety training					0.214 **	0.195 **	0.199 **
Safety compliance						0.085	0.094
Safety rules and procedures							−0.069
R	0.127	0.161	0.204	0.700	0.720	0.724	0.727
R^2	0.016	0.026	0.041	0.491	0519	0.524	0.528
Adjusted R^2	0.013	0.019	0.032	0.484	0.510	0.514	0.517

* $p < 0.05$; ** $p < 0.001$.

In the first three steps, the analysis revealed that the respondents' age [$F(1,298) = 4.885$, $p < 0.05$], sea service [$F(2,297) = 3.950$, $p < 0.05$], and tenure [$F(3,296) = 4.271$, $p < 0.01$] contributed significantly to the model and accounted for 3.2% of the variance. In the fourth step, communication was introduced in the model [$F(4,295) = 71.057$, $p < 0.001$], and the amount of explained variance increased by 45.1%. In the next steps, safety training perceptions [$F(5,294) = 63.356$, $p < 0.001$] and safety compliance [$F(6,293) = 53.651$, $p < 0.001$] were added, which explained 2.6% and 0.4% of the variance, respectively. In the final step, perceptions of safety rules and procedures quality were added [$F(7,292) = 46.650$, $p < 0.001$] and an additional 0.3% of the variance in the model was explained. Perceived communication was the strongest predictor of the quality of safety supervision.

5. Discussion

Previous studies that have looked at improving safety on board ships have concluded that safety can be improved through a variety of measures, such as the proper implementation of the ISM Code [44–46], development of safety systems (e.g., [47]), improvement of audit systems [48], and provision of adequate safety resources [49,50].

The aim of this study was to identify the shipboard safety factors, ISM-related [4], that may influence safety supervision practices, i.e., to investigate their impact on the quality of safety supervision in the maritime industry. From a practical point of view, safety supervision can be considered the last line of defense against occupational accidents and incidents. Therefore, these results have both theoretical and practical importance. The results showed that the variables explaining perceived safety communication and safety training can theoretically be considered statistically significant predictors of the quality of safety supervision.

The results of this study are consistent with previous research studies that emphasize the importance of safety communication for workplace safety in manufacturing facilities [21]. Furthermore, these findings support the results of a study that looked at accidents and incidents in the shipping industry and identified poor communication as one of the main causes [45,51]. However, the results of this study differ from those of other studies that have looked at safety-related incidents and in particular the importance of safety communication (e.g., [19,52]). The explanation for the different results could lie in the measures used in the questionnaires. The focus of the research on safety communication mentioned above was on the "communication atmosphere" within organizations, while the questionnaire used for this study included additional measures that were confirmed by the exploratory factor analysis, such as: the issue of resolving conflict situations on board, communication about safety rules and procedures at the start of employment for new staff, and communication in the form of praise for those who work in a safe manner and vice versa.

Based on the authors' expert opinions, the issue of resolving conflict situations on board is particularly important as modern merchant ships have a minimum crew, usually around 20–25 seafarers. If conflict situations are not resolved in a timely and appropriate manner, all forms of communication, including communication on safety issues, between the crew members concerned may be disrupted and the quality of safety supervision could be compromised.

Safety training was identified as the second most important predictor of safety supervision in this study. The explanation for safety training is straightforward and logical. If crew members are well trained in following safety rules and procedures or are able to use the appropriate personal protective equipment, it is reasonable to assume that the quality of safety supervision will be high. Although it is assumed that all seafarers are well trained, actual cases often show the opposite. This finding is consistent with the results of previous studies and suggests that the quality of safety training should be of a high level to prepare seafarers for the hazards on board [18,53]. In addition, the results of a recent study suggest that safety managers should improve the safety theory and theoretical background of training and emergency preparedness to achieve a better understanding of safety issues [54]. In addition, the results of the same study showed that safety training and emergency preparedness can improve crew routines, but not necessarily crew members' safety consciousness.

A recent study in two Chinese shipping companies looking at onboard safety supervision found that management efforts to improve safety compliance were perceived by crewmembers as a tool that led to increased workload, psychological pressure, and fatigue [55]. The results are similar to those where crewmembers perceived SMS compliance as less useful or irrelevant [45]. According to [54], it is safety communication that influences crewmember safety consciousness and the recommendation of the study is consistent adherence to ISM and MLC guidelines by safety managers. However, there is no clear evidence that safety managers do not implement these guidelines in practice.

The key may lie in individuals' perceived importance of safety. Due to the shortage of seafarers in the maritime industry and with the goal of saving time and resources, companies often outsource this task to crewing agencies. A recent study investigated this issue and concluded that the selection of crewing agencies, i.e., individual seafarers, should be based on the nature of the company culture [56]. According to the same authors, a successful relationship between the parties should lead to effective communication onboard, fewer misunderstandings, and effective training. Therefore, the recruitment policy of the industry should also be considered.

The study also aimed to investigate whether demographic characteristics (age of respondents, cumulative sea service time, and company tenure) can influence the quality of safety supervision. The results obtained showed that the regression coefficients of the demographic variables fell from statistically significant to not significant, indicating full mediation in the model.

6. Conclusions

As previous studies have shown, safety climate plays an important role in organizational efforts to improve workplace safety and promote safety behaviors in the maritime industry [11,18], as in other industries [13,14]. Our findings suggest that improved safety communication and safety training could influence the quality of safety supervision and consequently increase workplace safety on ships.

These findings highlight the importance of the ISM Code guidelines, which serve as guiding principles for all shipping organizations to make ships a safer workplace. In addition, the results of the study may be of importance to both management and practitioners. As Anderson [3] noted, the task of implementing ISM and developing a safety culture depends largely on the commitment of management structures. The task of management structures is thus twofold: first, to select employees who perceive safety communication and safety training as an important part of their daily work, and second, to create the necessary conditions for uninterrupted communication that contributes to a stronger safety culture throughout the shipping company. The model presented can serve as a guiding principle and can be applied not only in the shipping industry but also in all other high-risk industries.

However, a possible limitation of the study is that the respondents were only Croatian nationals. The reason why we state this as a possible limitation of the study lies in two facts: (1) there are only a few Croatian shipping companies that operate their ships worldwide, and (2) all the shipping companies mentioned have registered their ships under flags of convenience, which enables them to employ seafarers of other nationalities and cultures. Accordingly, it can be concluded that the vast majority of respondents work in a multicultural environment and that some cross-cultural influence among them is to be expected. Therefore, cross-cultural differences remain unknown. Recent studies have shown that there are cultural differences between different nationalities (e.g., [57]). Furthermore, future research should consider including additional variables such as safety motivation and safety consciousness to examine their influence on safety supervision.

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Assessment of Carbon Emission and Carbon Sink Capacity of China's Marine Fishery under Carbon Neutrality Target

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Abstract: Excessive carbon emissions will cause irreversible damage to the human living environment. Therefore, carbon neutrality has become an inevitable choice for sustainable development. Marine fishery is an essential pathway for biological carbon sequestration. However, it is also a source of carbon emissions. From this perspective, an in-depth assessment of the performance of carbon emissions and sinks from marine fisheries is required to achieve the goal of carbon neutrality. This paper measured the carbon emissions, carbon sinks, and net carbon emissions of marine fisheries in nine coastal provinces of China from 2005 to 2020 for the first time. Based on the calculation results, the log-mean decomposition index method was used to analyze the driving factors of net carbon emissions. The results suggested that, from 2005 to 2020, both the carbon emissions and carbon sinks of China's marine fisheries increased, and the net carbon emissions showed a downward trend. There were variations in the performance of carbon emissions, carbon sinks, and net carbon emissions in different provinces, and only Shandong could consistently achieve carbon neutrality. Fujian and Liaoning achieved carbon neutrality in 2020. In terms of the contribution of each factor, the industrial structure was the main positive driver, and carbon intensity was the main negative driver. Based on the empirical results, this paper suggested increasing the implementation of the carbon tax policy, establishing a farming compensation mechanism and promoting carbon emissions trading and international blue carbon trading. The results could give a reference for the energy conservation and emission reduction of marine fisheries while enhancing the ecological benefits of their carbon sinks and helping to achieve the carbon neutrality target.

Keywords: carbon neutral; marine fishery; carbon emission; carbon sink; net carbon emission; LMDI

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1. Introduction

Human activities have profoundly changed the natural environment in which they live. The growth of urbanization and industrialization has led to carbon emissions reaching a point where nature can hardly carry them. Carbon emissions refer to the emissions of greenhouse gases, of which carbon dioxide is the main greenhouse gas. Excessive carbon emissions can result in consequences such as ocean acidification, global warming, and extreme weather. This series of consequences seriously threatens the living environment and health of human beings [1,2]. Therefore, reducing carbon emissions has become an inevitable trend for the future development of all countries worldwide. The Paris Agreement initiation showed countries' determination to reduce greenhouse gas emissions [3]. In this context, China announced a "carbon neutrality" goal in 2020, aiming to achieve carbon neutrality by 2060. Carbon neutrality means balancing between emitting carbon and absorbing carbon from the atmosphere in carbon sinks [4,5]. Carbon neutrality is a huge driver of China's economic growth and transformation. Future scientific research, technological development, and other decisions need to consider carbon neutrality. In addition to relying on advanced technology [6], industrial structure upgrading, and optimization, carbon sequestration through marine fisheries is also an important path to achieving the goal of carbon neutrality [7]. Marine fisheries' carbon sinks can reduce atmospheric CO_2 concentrations directly or indirectly through production activities. In contrast to the high cost and difficulty of technological upgrading to form carbon sinks, marine fisheries' carbon sinks have lower costs and greater potential [8]. The development of ocean carbon sinks is of great significance to implementing a low carbon economy [9].

Therefore, under the goal of carbon neutrality, there is an urgent requirement to clarify how much carbon can be absorbed by China's marine fisheries, which will help to effectively use the ecosystem to absorb carbon and achieve long-term carbon storage in the ocean [10]. Although marine fisheries can form biological carbon sequestration, fisheries are also carbon emitters. Hence, net carbon emissions from marine fisheries need to be considered. If they can reach zero or negative values within a certain time frame, the goal of carbon neutrality will be achieved. Whether marine fisheries can achieve carbon neutrality is crucial for them to transform their traditional economic approach and achieve circular development of the marine economy [11]. Nevertheless, regarding China's current distribution of marine fisheries, the development is not balanced across regions [12]. The current status of net carbon emissions in various provinces needs to be analyzed to find the differences between provinces. Meanwhile, studying the net carbon emissions of marine fisheries in depth is not enough to understand the current status of the individual region. Considering the drivers of net carbon emissions is also necessary. When exploring the drivers of net carbon emissions, the extent of contribution of different factors should be systematically considered. The analysis results can help improve the ecological value of marine fisheries and provide a better "decarbonization space" for the sustainable development of the marine economy [13].

Consequently, the research in this paper makes the following contributions. First, this paper assessed the Chinese provinces' net carbon emissions based on the calculation of carbon emissions and carbon sinks of marine fisheries, led by the carbon neutrality target. Second, in the process of calculating net carbon emissions from marine fisheries, this paper used a modified carbon sink accounting system and considered carbon emissions generated from the operation of motorized farming fishing vessels. Third, using the log-mean decomposition index (LMDI) model, this paper analyzed the drivers of net carbon emissions and evaluated the contributions of carbon intensity, industrial structure, industrial efficiency, and industrial scale to the level of net carbon emissions in China. Theoretically, this paper has bridged the gap in existing marine fisheries research. Based on the calculation results of carbon emissions and carbon sinks of marine fisheries, this paper proposed targeted countermeasures for the development of marine fisheries in China. The research methods and results offered theoretical references for the development of marine fisheries. In practical applications, the findings supported energy saving and emission reduction in marine fisheries and helped to enhance the ecological function of carbon sinks in marine fisheries. By integrating with marine policies, this paper contributed to the early achievement of the carbon neutrality target for China's marine fisheries. The rest of the paper is structured as follows. The second section provides a review study of the relevant literature. Section 3 introduces the methodology and data sources of this paper. Section 4 analyzes the empirical results. Section 5 provides some extended discussion of the results. Section 6 is the conclusion and policy recommendations of this paper.

2. Literature Review

Currently, many scholars have studied the carbon emissions and carbon sinks of marine fisheries. There are, however, few in-depth studies on net carbon emissions. Yue et al. [14] explored the carbon balance status of China's marine fisheries and conducted a regional characterization. However, they did not further explore the drivers of the carbon balance state. Guan et al. [13] conducted a decoupling analysis of net carbon emissions and economic growth in marine aquaculture, yet an independent analysis of net carbon emissions from different regions was missing. Therefore, in addition to their studies, this section focuses on sorting out the literature on carbon emissions and carbon sinks. Correctly handling the neutral relationship between carbon emissions and carbon sinks is the key to facilitating the sustainable development of marine fisheries.

As an element closely related to our lives, carbon emissions have been a hot research topic. In recent years, scholars have focused on carbon emission reduction, carbon tax policy, carbon emission transfer, and carbon emission trading as the main topics on carbon emissions. Their calculation methods for carbon emissions included carbon footprint [15], system dynamics [16], input–output analysis [17], and life cycle assessment [18]. Wang et al. [19] measured the carbon emission intensity of Chinese agriculture and proposed a regional carbon reduction strategy. Sun et al. [20] analyzed the carbon emission transfer and reduction problem among companies in the supply chain based on the game theory. Xu and Long [21] studied the impact of carbon tax policies on the economy and carbon emissions and concluded that carbon taxes inhibit economic growth and carbon emissions. Sun et al. [22] explored the spatial characteristics of provincial carbon emission transfers and their economic spillover effects in China. Hua et al. [23] examined how companies can manage their carbon footprint in inventory management under the carbon trading mechanism. Guo et al. [24] dissected whether carbon emissions trading has promoted carbon finance and reduced carbon emissions. Based on the regional differences and spatial–temporal evolution trends of carbon emission intensity in China, Zhang and Fan [25] constructed the emission reduction effectiveness criteria of the carbon emission trading mechanism. Research on carbon emissions also involves multiple industries, such as electric power [26], construction [27], and transportation [18]. For marine fisheries, Kim et al. [28] estimated the changes in greenhouse gas emissions and emission costs from capture fisheries using a steady-state bioeconomic model. Ghosh et al. [15] studied the carbon emissions from marine fisheries fuel and electricity consumption by determining the carbon footprint. Wang and Wang [29] explored the relationship between carbon emissions and the economic output of marine fisheries.

Existing research on carbon sinks has focused on forests, cities, grasslands, and wetlands. Maia et al. [30] investigated long-term trends in carbon stocks and sinks based on data from monitored forest sites. Shi et al. [31] used the stock approach to measure the amount and value of forest carbon sinks in China. Xu et al. [32] studied the influence of urban characteristics on the spatial variation of urban carbon sinks. Smith [33] explored whether grasslands can act as permanent carbon sinks. Bu et al. [34] assessed carbon sinks in wetland ecosystems. At the same time, more and more scholars recognize the value of “blue carbon”, including the economic and ecological benefits generated by carbon sinks [13]. The most common method for calculating marine sinks was the “removable sink” model [8,35]. Chung et al. [36] suggested that the appropriate use of macroalgae could reduce greenhouse gas emissions. Bao [10] explored the key elements of assessing ocean carbon sinks. They concluded that the age scale of carbon pools and the timing of carbon sink processes were key elements in assessing ocean carbon sinks. Ren [8] estimated the capacity of removable carbon sinks in China’s mariculture industry and analyzed the influence of structural and scaling factors on it using the LMDI model. Liu et al. [37] proposed a method for calculating ocean carbon sinks that considered both the type of carbon sink and the time scale of its characteristic carbon storage cycle. Jones et al. [38] explored the interactions between the mariculture industry and its surrounding marine ecosystem. In addition to assessing and accounting for carbon sinks, scholars have also made predictions [39] and conducted impact factor analyses [7] of carbon sinks in marine fisheries.

By sorting out the existing literature, it can be found that most scholars have studied carbon emissions and carbon sinks in different industries separately. Studies involving net carbon emissions from marine fisheries have not delved into the driving factors behind them. Instead, motivated by the goal of carbon neutrality, research on marine fisheries should focus on net carbon emissions and their drivers. The gap in this research area also provides an opportunity for an in-depth study of this paper. Therefore, starting from the carbon neutrality target, this paper studied the performance of marine fishery carbon emissions and carbon sinks in China’s coastal provinces, and analyzed whether their net carbon emissions could achieve the ecological function of marine fishery carbon sinks. Based on the calculation results, this paper constructed a driving factor decomposition model of net carbon emissions and explored the reasons behind these results.

3. Materials and Methods

3.1. Calculated Methods for Carbon Emissions

The main source of carbon emissions from marine fisheries is the fuel consumption of marine motorized fishing vessels during the production process. Since the "carbon" in the definition of carbon neutrality is CO_2, this paper adopted the conversion formula to calculate the emission and sink of CO_2. The calculation process of carbon emissions refers to the calculation method of fossil fuel combustion emissions CO_2 proposed by the Oak Ridge National Laboratory in the United States. The calculation formula is as follows [11]:

$$C = \sum_{m=1}^{7} \mu_m \cdot P_m \cdot h \tag{1}$$

where C is the coal consumption, m is the different operation modes of fishing boats, μ is the oil consumption coefficient of fishing boats with different operation modes, P is the main engine power of fishing boats with different operation modes, and h is the fuel oil conversion coefficient of standard coal, which is 1.4571.

$$Q_c = Q_E \cdot F_C \cdot C \cdot \delta \tag{2}$$

where Q_c is the amount of carbon, Q_E is the effective oxidation fraction and takes the value of 0.982, F_C is the amount of carbon per ton of standard coal and takes the value of 0.73257, and δ is the ratio of CO_2 emitted from fuel oil to coal combustion under the same heat energy obtained and is 0.813.

$$Q_{co_2} = Q_C \cdot \omega \tag{3}$$

where Q_{co_2} is the amount of CO_2 released and ω is the constant for carbon to CO_2 conversion (based on the relative atomic mass), which takes the value of 3.67.

3.2. Calculated Methods for Carbon Sinks

The main sources of carbon sinks in marine fisheries are shellfish and algae farming. The "removable carbon sink" model proposed by Tang et al. [40] includes only the carbon that is fixed in shellfish and algal organisms and eventually removed from the water column through fisheries harvest. This calculation ignores the carbon sinks formed by the release of particulate organic carbon (POC) and dissolved organic carbon (DOC) during the growth of shellfish and algae. Therefore, the carbon sink estimation model used in this paper refers to Yang et al.'s [7] research results.

3.2.1. Estimation of Carbon Sinks of Mariculture Shellfish

Through carbon source tracking, it was found that the main source of carbon in shellfish shells is dissolved inorganic carbon (DIC) in seawater. About 10% to 20% of the carbon comes from marine POC and DOC. Furthermore, more than 97% of the carbon in soft tissue comes from POC, DOC, or marine sediments in seawater [41]. The carbon in both seawater POC and DOC is organic carbon. These carbons are directly absorbed in shellfish organisms and cannot directly reduce CO_2 in the atmosphere or DIC in seawater and other inorganic carbons, so they are not included in the carbon sink estimation model. This part of carbon is directly absorbed in shellfish organisms and cannot directly reduce CO_2 in the atmosphere or DIC in seawater and other inorganic carbons, so it is not included in the carbon sink estimation model. Carbon from marine sediments is stored relatively long term and stably in seawater, and removing it from water by harvesting shellfish does not affect reducing CO_2 in the atmosphere and should not be included in carbon sink estimation models. Therefore, in this paper, part of the carbon in shells and carbon in soft tissues of shellfish are not considered as carbon sinks.

According to the shellfish carbon budget equation, shellfish total dietary carbon (*TDC*) can be decomposed into fecal carbon (*FC*), excretion carbon (*EC*), respiration carbon (*RC*), and growth carbon (*GC*). Among them, the proportion of *RC* in *TDC* is relatively stable, generally about 50%. *FC* and *EC* together accounted for 25% of shellfish *TDC*, while *GC* accounted for about 25%. The ratio of *FC* + *EC* to *GC* is about 1, from which the *POC* released during shellfish growth can be deduced.

In summary, the total carbon sink of marine shellfish aquaculture can be calculated based on the following model:

$$C_i^s = P_i^{sh} \cdot R_i^s \cdot w_i^s \cdot (1 - \varepsilon_i) \tag{4}$$

$$C_i^{st} = P_i^{sh} \cdot R_i^{st} \cdot w_i^{st} \tag{5}$$

$$C_i^{POC} = \left(\frac{C_i^s}{1 - \varepsilon_i} + C_i^{st} \right) \cdot \frac{FC + EC}{GC} \cdot \gamma^{POC} \tag{6}$$

$$TC^{sh} = \sum_i \left(C_i^s + C_i^{POC} \right) \tag{7}$$

$$TC_{CO_2}^{sh} = TC^{sh} \cdot \omega \tag{8}$$

where the carbon sink of shellfish cultivation TC^{sh} consists of two parts: the shell carbon sink C_i^s and the carbon sink C_i^{POC} formed by the release of *POC* during the growth of the shellfish. ω is a constant for converting carbon into CO_2. Carbon C_i^{st} in soft tissue is not considered as a carbon sink. i represents the species of shellfish. P_i^{sh} represents the shellfish yield (wet weight), R_i^s represents the dry weight ratio of the shell, and w_i^s represents the carbon content of the shell. $1 - \varepsilon_i$ represents the conversion factor of shell carbon source, and ε_i represents the proportion of carbon in the shell from organic carbon or marine sediment to the total shell carbon. R_i^{st} represents the dry weight ratio of soft tissue, and w_i^{st} represents the carbon content of soft tissue. C_i^{POC} is based on shellfish growth carbon data, measured using the scaling relationship of $\frac{FC+EC}{GC} = 1$ in the carbon balance equation. γ^{POC} represents the conversion ratio from POC to carbon sinks.

3.2.2. Estimation of Carbon Sinks of Mariculture Algae

The main carbon sequestration mechanism of macroalgae is photosynthesis, but the carbon that is ultimately removed from the water is not all of the macroalgae's photosynthetic productivity. Due to effects such as kinetic erosion and sedimentation during harvest, macroalgae release a large amount of *POC* into the water column, releasing about 19% of their photosynthetic productivity. In addition, during the macroalgae growth, *DOC* is released into the water column, and the amount released is about 5% of their photosynthetic productivity. Part of the *POC* and *DOC* released by macroalgae to the water body will be used by marine organisms and returned to the atmosphere by microbial decomposition and respiration. The other part is converted to marine sediment or recalcitrant dissolved organic carbon (*RDOC*) by mechanisms such as vertical transport and sedimentation, thus storing carbon in the ocean for a long time to form a carbon sink.

Therefore, the carbon sink of marine algae culture includes the carbon sink of algae and the carbon sink formed by algae through the release of *POC* and *DOC*. The total carbon sink of mariculture algae can be measured using the following equation:

$$C_j^a = P_j^{al} \cdot w_j^a \tag{9}$$

$$C_j^{POC} = C_j^a \cdot \frac{\alpha}{1 - \alpha - \beta} \cdot \gamma^{POC} \tag{10}$$

$$C_j^{DOC} = C_j^a \cdot \frac{\beta}{1-\alpha-\beta} \cdot \gamma^{DOC} \tag{11}$$

$$TC^{al} = \sum_j \left(C_j^a + C_j^{POC} + C_j^{DOC} \right) \tag{12}$$

$$TC_{CO_2}^{al} = TC^{al} \cdot \omega \tag{13}$$

where the total carbon sink of seawater algae cultivation TC^{al} consists of the algal bodies' carbon sink C_j^a, the carbon sink C_j^{POC} and C_j^{DOC} formed by the algae through the release of POC and DOC. ω is the constant for the conversion of carbon to CO_2 and j represents the species of algae. P_j^{al} is algal production (dry weight) and w_j^a is algal carbon content. α and β represent the share of POC and DOC released during algal growth in photosynthetic productivity, respectively. γ^{POC} and γ^{DOC} reflect the rate at which POC and DOC released by organisms are eventually converted into carbon sinks, respectively.

3.3. Calculation of Net Carbon Emissions

Based on the carbon emission characteristics of marine fishery production activities, the formula for calculating the net carbon emissions of marine fisheries can be obtained.

$$C_{net} = Q_{CO_2} - \left(TC_{CO_2}^{sh} + TC_{CO_2}^{al} \right) \tag{14}$$

That is, the net carbon emissions from marine fisheries are the difference between carbon emissions from fuel consumption by motorized fishing vessels and the carbon sinks formed by shellfish and algae farming.

3.4. Decomposition Analysis of Influencing Factors of Net Carbon Emission

The main methods for decomposing the factors influencing carbon emissions include the environmental Kuznets curve (EKC), IPAT model, STIRPAT model, and LMDI method. The EKC approach shows an inverted U-shaped relationship between environmental quality and income, limited by the relationship and indicators. IPAT is a linear analytical model, but the environment and the level of social development are often not simply linearly related. The STIRPAT model overcomes the limitations of the homogeneous linear relationship of the IPAT model. However, it cannot wholly decompose the residuals. Compared to other methods, the LMDI method can complete decomposition without residuals and is less restrictive on the data. Hence, this paper uses the LMDI method to identify the drivers of net carbon emissions [29]. Previously, the net carbon emissions from marine fisheries were decomposed into the following form, drawing on the principle of two-sided constancy of Kaya's constant equation [42].

$$C_{net} = \frac{C_{net}}{G} \cdot \frac{G}{Y} \cdot \frac{Y}{E} \cdot E \tag{15}$$

where C_{net} is the net carbon emission of marine fisheries, G is the economic output value of marine fisheries, Y is the fishing production, and E is the number of employees. By Equation (15), the net carbon emissions of marine fisheries can be decomposed into four factors: carbon intensity (C_{int}), industrial structure (C_{str}), industrial efficiency (C_{eff}), and industrial scale (C_{sca}).

$$C_{net} = C_{int} \cdot C_{str} \cdot C_{eff} \cdot C_{sca} \tag{16}$$

In this paper, the change in net carbon emissions from the base year to the target year ΔC_{net} is decomposed using the LMDI additive decomposition in the form of Equation (17).

$$\Delta C_{net} = C_{net}^{t+1} - C_{net}^{t} = \Delta C_{int} + \Delta C_{str} + \Delta C_{eff} + \Delta C_{sca} \tag{17}$$

In Equation (17), t represents the year. The net carbon emissions are decomposed into four factors, and the impact of each factor on the net carbon emissions can be measured specifically. The detailed calculations on these four factors are as follows:

$$\Delta C_{int} = L\left(C_{net}^{t+1}, C_{net}^{t}\right) \cdot \ln\left(\frac{C_{int}^{t+1}}{C_{int}^{t}}\right) \tag{18}$$

$$\Delta C_{str} = L\left(C_{net}^{t+1}, C_{net}^{t}\right) \cdot \ln\left(\frac{C_{str}^{t+1}}{C_{str}^{t}}\right) \tag{19}$$

$$\Delta C_{eff} = L\left(C_{net}^{t+1}, C_{net}^{t}\right) \cdot \ln\left(\frac{C_{eff}^{t+1}}{C_{eff}^{t}}\right) \tag{20}$$

$$\Delta C_{sca} = L\left(C_{net}^{t+1}, C_{net}^{t}\right) \cdot \ln\left(\frac{C_{sca}^{t+1}}{C_{sca}^{t}}\right) \tag{21}$$

$$L\left(C_{net}^{t+1}, C_{net}^{t}\right) = \begin{cases} \frac{C_{net}^{t+1} - C_{net}^{t}}{lnC_{net}^{t+1} - lnC_{net}^{t}} \; C_{net}^{t+1} \neq C_{net}^{t} \\ C_{net}^{t+1} \; or \; C_{net}^{t} \; C_{net}^{t+1} = C_{net}^{t} \\ 0 \; C_{net}^{t+1} = C_{net}^{t} = 0 \end{cases} \tag{22}$$

3.5. Data Sources

In this paper, nine coastal provinces in China were selected for the study. Hong Kong, Macau, and Taiwan were excluded due to data availability difficulties. Shanghai and Tianjin were also excluded from this paper due to the small size of their marine fishery industries and the large gap with other provinces. The data required for the calculation, such as shellfish and algae production, were obtained from the China Fishery Statistical Yearbook and the China Marine Economic Statistical Yearbook. The parameters of shellfish and algae referred to the research results of [7,8,40,43]. The parameters used are listed in Table 1.

Table 1. Biological parameters used in the model (%).

Species	The Dry Weight Ratio of Shells (%)	The Carbon Content of Shells (%)	The Dry Weight Ratio of Soft Tissue (%)	The Carbon Content of Soft Tissue or Algae (%)
Shellfish				
Crassostrea gigas	63.80	11.52	1.30	44.90
Ruditapes philippinarum	44.65	11.40	7.67	42.84
Chlamys farreri	56.58	11.44	7.32	43.87
Mytilus edulis	70.64	12.68	4.63	45.98
Sinonovacula constricta	64.78	13.24	6.62	44.99
Scapharca subcrenata	68.64	11.29	5.83	45.86
Others	61.52	11.93	5.56	44.74
Algae				
Laminaria japonica				31.20
Undaria pinnatifida				30.48
Gracilaria verrucosa				24.50
Porphyra tenera				29.09
Gelidium amansii				29.48
Sargassum fusiforme				23.87
Enteromorpha clathrata				29.04
Others				28.24

To calculate the carbon sink of marine fisheries, process parameters, such as the shell carbon source conversion coefficient $1 - \varepsilon$, POC carbon sink conversion coefficient

γ^{POC}, and DOC carbon sink conversion coefficient γ^{DOC}, are also needed. Referring to Quan et al. [41], the source of carbon in shells as organic carbon or marine sediment accounted for about 20% of the total carbon in shells, and the conversion coefficient $1-\varepsilon$ for shell carbon sources was 0.8. Drawing on [7], the values of γ^{POC} and γ^{DOC} were 1, and the values of α and β were 0.19 and 0.05, respectively. To calculate carbon emissions from marine fisheries, fuel consumption factors for fishing vessels with different modes of operation are also needed. The specific oil consumption coefficient was based on the Reference Standard for the Measurement of Oil Consumption for Domestic Motor Fishing Vessel Oil Price Subsidy issued by the Ministry of Agriculture of China. The oil coefficient for trawl was 0.480(t/kw), for seine was 0.492(t/kw), for gill net was 0.451(t/kw), for stow net and fishing gear was 0.328(t/kw), for others was 0.312 (t/kw), and for farm fishing vessel was 0.225(t/kw).

4. Results

4.1. Spatial–Temporal Evolution Characteristics at the National Level

Analyzing the data related to carbon emissions and carbon sinks at the national level can provide a theoretical basis for the government to formulate policies. The carbon emissions, carbon sinks, and net carbon emissions of marine fisheries in China from 2005 to 2020 were calculated and the results are shown in Table 2. From 2005 to 2020, China's carbon emissions from the marine fishery industry increased by 12.75% from 16.647 million tons to 18.770 million tons. Carbon sinks increased from 7.860 million tons to 11.667 million tons, an increase of 48.44%. Net carbon emissions decreased from 8.786 million tons to 7.104 million tons, a reduction of 19.14%. It can be found that the carbon sinks grew more than the carbon emissions, so the net carbon emission was reduced. This result indicates that the pressure on the environment from China's marine fisheries is decreasing but there is still a certain distance from the goal of carbon neutrality. The increase in carbon sinks far outweighed carbon emissions, suggesting that China has made many efforts to reduce carbon emissions from marine fisheries.

Table 2. Estimation results of net carbon emissions from marine fisheries in China from 2005 to 2020 (10^5 t/year).

Year	Carbon Emissions	Carbon Sinks	Net Carbon Emissions
2005	166.47	78.60	87.86
2006	169.73	81.56	88.17
2007	174.53	72.54	101.99
2008	181.21	73.86	107.35
2009	183.22	77.33	105.89
2010	182.81	81.39	101.42
2011	185.38	84.64	100.74
2012	186.11	89.41	96.70
2013	190.81	94.47	96.34
2014	196.80	99.49	97.31
2015	201.95	103.00	98.96
2016	200.39	107.39	93.00
2017	193.17	109.28	83.90
2018	191.73	111.15	80.58
2019	189.08	113.69	75.39
2020	187.70	116.67	71.04

Figure 1 shows the trends of carbon emissions, carbon sinks, and net carbon emissions from marine fisheries in China. As can be seen from Figure 1, the overall trend of carbon emissions from marine fisheries rose and fell, reaching a peak in 2015. In 2016, China proposed the 13th Five-Year Plan for National Fisheries Development. Since the implementation of the plan, under the principle of "ecological priority and green development", China's marine motorized fishing vessels have been reduced, and the green development of marine fisheries has been promoted. The reduction in carbon emissions illustrates the effectiveness of this planning. The overall trend of carbon sinks from marine fisheries was on the rise but there was a decline in 2007. During the 11th Five-Year Plan and 12th Five-Year Plan periods, the carbon sink capacity of China's marine fishery increased significantly. In this period, the Chinese government attached great importance to the work of the "three issues of agriculture, the countryside and farmers" and adopted a policy of "high investment" in marine fisheries. The government had proposed policies, such as subsidies for fisheries diesel fuel and fishery resource protection. All these policies have contributed to the improvement of the carbon sink capacity of marine fisheries. By the 13th Five-Year Plan period, the increase in carbon sinks had slowed down. A possible reason was that the expansion of the scale of shellfish and algae farming resulted in too high a farming density, which reached the upper limit of the environmental carrying capacity of marine resources. The policy direction began to change at this time, with the government focusing on optimizing and upgrading the marine industry and implementing a policy of negative growth in offshore fishing production. Net carbon emissions were on an overall downward trend, with one significant increase in 2007. This rise was due to the decline in carbon sinks in 2007. From 2018 onwards, the downward trend in net carbon emissions began to stabilize.

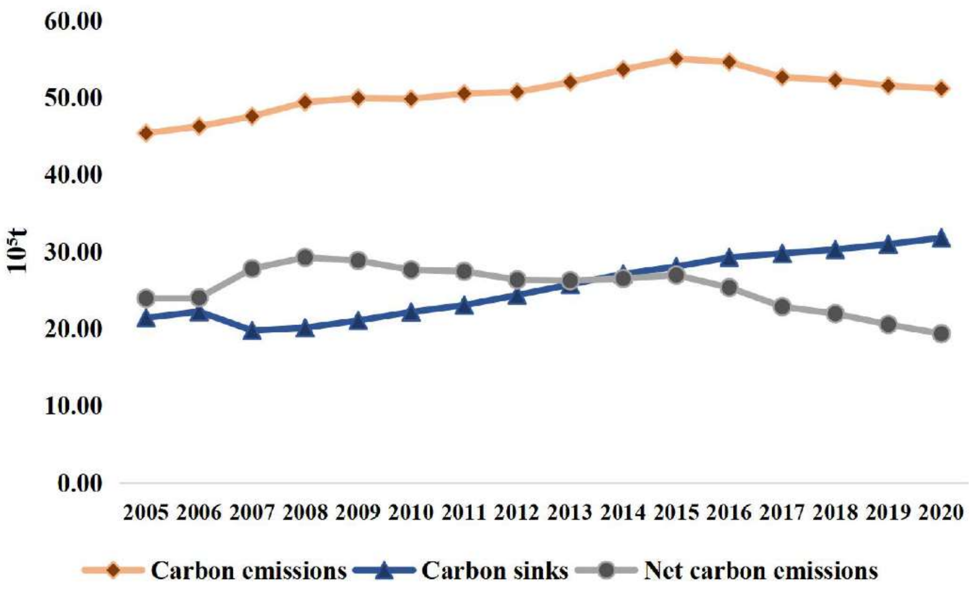

Figure 1. Changes in marine fishery carbon emissions, carbon sinks, and net carbon emissions from 2005 to 2020 (10^5 t/year).

4.2. Spatial–Temporal Evolution Characteristics from the National Perspective

The coastal provinces differ in their level of economic development, geographic location, and climatic conditions. Therefore, they also show different locational characteristics in the development of marine fisheries. To further understand the spatial and temporal evolution of carbon emissions, carbon sinks, and net carbon emissions, the following analysis is carried out at the provincial level.

4.2.1. Provincial Characteristics of Carbon Emissions

Table 3 shows that, among the nine Chinese coastal provinces, only Guangdong and Guangxi showed a decreasing trend in overall carbon emissions. Carbon emissions increased in the remaining seven provinces, and the most significant increase was seen in Hainan. In 2005, Zhejiang had the largest carbon emissions, reaching 4.744 million tons. While this total was much higher than other provinces, Zhejiang's growth and increment were better compared with other provinces. The province with the least carbon emissions was Hebei, which was also related to the smaller farming scale in Hebei. The increase in

Hebei was relatively large, which indicates that Hebei's marine fishery needs to increase the implementation of energy conservation and emission reduction. In 2020, the provinces with the most and least carbon emissions were still Zhejiang and Hebei, but the gap between the two had narrowed. The province with the largest increase in carbon emissions was Hainan. Although Hainan's carbon emissions were not high among the nine provinces, they had almost doubled from 2005 to 2020. Therefore, the carbon emission reduction work of China's marine fishery can be appropriately tilted to Zhejiang and Hainan.

Table 3. Increased carbon emissions of the marine fishery.

Provinces	Carbon Emissions (10^5 t/year)		Rate of Increase in Carbon Emissions (%)
	2005	2020	
Hebei	3.86	5.12	32.73
Liaoning	14.11	18.28	29.58
Jiangsu	7.03	8.36	18.90
Zhejiang	47.44	48.41	2.06
Fujian	23.52	32.75	39.26
Shandong	20.88	23.94	14.67
Guangdong	29.94	23.56	−21.32
Guangxi	9.84	8.58	−12.83
Hainan	9.85	18.70	89.79

Figure 2 can reflect the trend of carbon emissions in nine provinces during this period. Regionally, the northern provinces include Liaoning, Hebei, and Shandong; the eastern provinces include Jiangsu and Zhejiang; and the southern provinces include Fujian, Guangdong, Guangxi, and Hainan. Carbon emissions were increasing in both the northern and eastern provinces, with the southern provinces performing better than the other two regions.

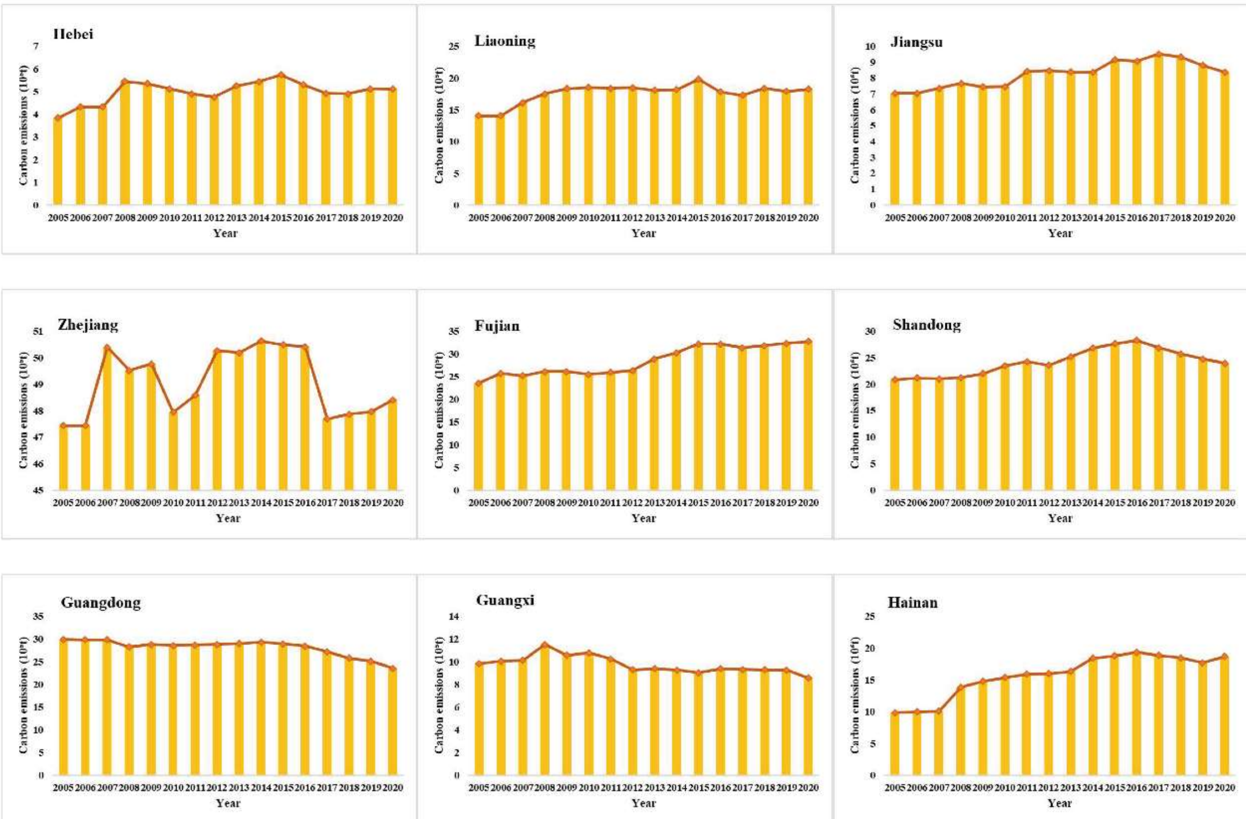

Figure 2. Changes in carbon emissions from the marine fishery industry in coastal provinces from 2005 to 2020.

Most of the provinces showed slight fluctuation, but the trend of fluctuation was obvious in Zhejiang and Hebei. Since 2005, Zhejiang has implemented the upgrading and technological transformation of its shipbuilding industry, erasing the former of its shipbuilding as "small, scattered and low". However, the rapid development of Zhejiang's shipbuilding enterprises also made its carbon emissions be firmly at the forefront of China. In 2007 and 2012, there was a significant increase in carbon emissions in Zhejiang. In 2011, the State Council of China approved the Zhejiang Marine Economic Development Demonstration Zone Plan, which elevated the construction of marine economic development demonstration zones to a national strategy. This plan has driven the expansion of factory farming areas in Zhejiang, leading to a rapid increase in carbon emissions. Aquaculture engineering and equipment integration support was not enough, and it restricted, to a certain extent, the implementation of carbon emission reduction in Zhejiang marine fisheries. In 2008, Hebei's carbon emissions increased significantly. On the one hand, Hebei continued to promote factory farming, excellent breeding selection, and other technologies. On the other hand, Hebei's investment in science and technology for marine fisheries was weak. These factors led to notable fluctuations in Hebei's carbon emissions. During the 11th Five-Year Plan period, Hebei promoted the transformation of marine fishery development from a quantity–speed type to a quality–benefit type. As a result, Hebei's carbon emissions reduced for a period, starting in 2008. Yet, the shortage of scientific and technical personnel and the outdated instrumentation of Hebei's marine fisheries caused a high growth rate of its carbon emissions.

Guangdong's carbon emissions were on a steady downward trend. As a major aquatic province in China, Guangdong's factory farming area was expanding. Nevertheless, Guangdong's carbon emissions decreased rather than increased, indicating the healthy development of Guangdong's marine fisheries. Guangdong strictly controlled its fishing intensity, promoted high-yield and low-consumption operations, and vigorously developed "deep blue fisheries" to achieve resource conservation and environmental friendliness. In addition to Guangdong, the carbon emissions of Guangxi were also declining. Guangxi had only one significant increase in emissions in 2008. The power of motorized fishing vessels in Guangxi was high that year, and then it started to fall back. In recent years, the marine fishing system in Guangxi gradually became more established, and the structure of fishing vessel operations became more reasonable, so carbon emissions showed a decreasing trend. Guangxi actively established fishery science and technology innovation platforms and accelerated the technical research and promotion application of marine fishery. Guangxi has a wealth of marine fisheries resources but they are currently underutilized and have great potential for development. When vigorously developing these fishery resources, Guangxi needs a good resource and ecological monitoring system to ensure the smooth development of the fishery.

The carbon emissions of Fujian and Hainan had been growing steadily. Fujian started to build the modern marine industry development base in 2009, which provided an opportunity to develop its marine fishery. Fujian has abundant water resources and a relatively complete fishery infrastructure in terms of fishery development. However, in developing marine fisheries, Fujian should pay attention to industrial structure optimization and expand its advantages. Hainan has been continuously optimizing the internal structure of fisheries and accelerating infrastructure construction in recent years. However, due to insufficient investment in fishery science and technology and a lack of talents, there was still a big gap between the development of its fishery and the more advanced provinces. Consequently, Hainan needs to increase investment in scientific research, strengthen the support force of science and technology, and control carbon emissions while developing marine fisheries.

The carbon emissions of Liaoning, Jiangsu, and Shandong were also fluctuating, but the fluctuation was not as noticeable. These provinces all attached great importance to the development of marine fisheries but were still searching for a development model suitable for themselves. During the 13th Five-Year Plan period, Liaoning issued the "Guiding

Opinions on the Development of Fishery Industry in Liaoning Province", highlighting that Liaoning needs to speed up the transformation of the fishery development model. In this period, Liaoning has increased scientific investment in areas such as marine engineering equipment and energy, and it has carried out essential technology research. New fishery species, marine robots, and other marine science and technology achievements have emerged one after another. As a result, there was a period of decline in Liaoning's carbon emissions from 2016 onwards. Liaoning has a good foundation of marine resources and is actively developing ecologically healthy aquaculture and sustainable fishing. However, while developing marine fisheries, Liaoning needs to speed up the construction of fishery infrastructure and reduce the pollution of carbon emissions to the environment. As an important part of the Yangtze River Delta region, Jiangsu has convenient logistics channels for developing marine fisheries. Jiangsu released a special action plan for marine fisheries in 2017 stating the aim of reducing the environmental impact of fisheries production. Jiangsu launched a fishing boat renovation program. Jiangsu eliminated old fishing boats, renovated several energy-consuming and inefficient fishing boats, updated a group of high-quality marine fishing boats, and completed the establishment of safety equipment for fishing boats. Consequently, carbon emissions in Jiangsu declined from 2017 onwards. Since the implementation of the marine fishing vessel renewal project in 2012, Shandong has improved the quantity and quality of fishing vessels through construction and renovation. As a result, there was a marked increase in carbon emissions in Shandong. In 2016, Shandong introduced the policy of oil price subsidy for fisheries fishing and aquaculture. This policy guided the fishing fishermen to reduce the number of vessels and to switch to production and ecological restoration, so that the number and power of fishing vessels were further reduced and fishing intensity was effectively controlled. The carbon emissions of Shandong's marine fisheries have also been gradually reduced since 2016.

It can be noted that the fishery development gap between the provinces was gradually decreasing. Different provinces should rely on their resource endowments to seize the opportunity for marine fisheries development. While developing marine fisheries, provinces need to pay attention to the green and low-carbon concepts, form a stable development space, and reduce the environmental pressure on the ocean.

4.2.2. Provincial Characteristics of Carbon Sinks

As shown in Table 4, only the overall carbon sink of Hainan was on a decreasing trend. The remaining eight provinces saw an increase in carbon sinks, and Hebei had the most significant increase. In 2005, Shandong's carbon sink was the largest, reaching 2.247 million tons. Hainan had the lowest carbon sink at 0.047 million tons, and its sink was still declining. In 2020, Fujian surpassed Shandong as the largest carbon sink, reaching 3.506 million tons. Hainan still had the lowest carbon sink, with only 0.018 million tons. The gap in carbon sinks between the coastal provinces was growing. The province with the largest increase in carbon sinks was Hebei, which almost doubled its carbon sinks in 2020 compared to 2005. In terms of both the number and the growth rate of carbon sinks, Hainan was lagging. Therefore, the shellfish and algae aquaculture in China's marine fisheries requires increased efforts to promote Hainan.

Figure 3 reflects the changing trend of carbon sinks in nine coastal provinces from 2005 to 2020. The carbon sinks in the northern provinces of Hebei, Liaoning, and Shandong fluctuated and eventually showed an upward trend. The carbon sink values of Jiangsu and Zhejiang in the eastern provinces were not as good as those of other regions but were on the rise as a whole. Fujian has an abundant and steadily increasing carbon sink among the southern provinces.

The fluctuation trends of Hebei, Liaoning, and Hainan were evident. Shellfish farming is a significant pillar of Hebei's fishing industry. Due to the rapid expansion of shellfish and algae farming in the northern marine economic circle during the 12th Five-Year Plan period, Hebei's carbon sink increased steadily from 2011 to 2015. The expansion of the farming scale had led to high farming density in local areas of Hebei, approaching the upper limit of the carrying capacity of the marine environment. The environmental degradation of the sea area threatened the sustainable development of Hebei's marine fisheries, and, as a result, Hebei's carbon sink began to decline significantly in 2016. Liaoning published and implemented the Liaoning Modern Sea Ranch Construction Plan in 2011. Focusing on the goal of marine pasture construction, Liaoning carried out actions such as resource restoration and sea farming to guarantee the development of its farming scale. However, the environmental degradation of the northern marine economic zone had also affected shellfish and algae farming in Liaoning, leading to fluctuations in its carbon sink. Hainan's marine economy has been focused on developing coastal tourism. With the construction of an international tourism island in Hainan, the land for fishing in Hainan was gradually reduced and the space for fishing development was squeezed. At the same time, the development of the Hainan farming industry accelerated the eutrophication of coastal waters, which negatively affected the ecological environment of coastal waters and restricted the sustainable development of the farming industry. As a result, the carbon sink of Hainan started to decline sharply in 2017, which eventually resulted in the carbon sink decreasing instead of rising.

Table 4. Increased carbon sinks of the marine fishery.

Provinces	Carbon Sinks (10^5 t/year)		Rate of Increase in Carbon Sinks (%)
	2005	2020	
Hebei	1.16	2.30	99.01
Liaoning	14.37	18.87	31.34
Jiangsu	2.64	4.24	61.06
Zhejiang	4.80	8.12	69.08
Fujian	19.45	35.06	80.24
Shandong	22.47	31.98	42.33
Guangdong	9.58	10.62	10.80
Guangxi	3.67	5.29	44.22
Hainan	0.47	0.18	−61.57

The overall upward trend in Zhejiang, Fujian, Shandong, and Guangxi was relatively stable. As a pilot province for the development of China's marine economy, the farming industry in Zhejiang has more development opportunities. In the 13th Five-Year Plan for marine ecological protection in Zhejiang Province, the government emphasized the need to actively develop shallow sea shellfish and algae ecological health culture models. Zhejiang implemented the shallow marine aquaculture space expansion project, guided the seawater pond recirculating water aquaculture and industrial recirculating water aquaculture, and developed offshore intelligent deep-water nets, large seine nets, and block nets. Consequently, between 2016 and 2020, the carbon sink in Zhejiang achieved rapid growth. With the development of port-side industries and accelerated urbanization in coastal areas, Fujian's marine fisheries were gradually withdrawn from some traditional production areas. The fishery showed a trend of gradually increasing aquaculture output and decreasing fishing output yearly. To achieve sustainable growth of carbon sinks, Fujian should strengthen the construction of aquaculture facilities. Shandong has a vast ocean space and huge development potential. In recent years, the mariculture structure of Shandong was gradually optimized and production was steadily increased. However, in 2019 Shandong's carbon sink had a fallback. Shandong can further improve the fisheries standards system and enhance the quality and safety of its aquaculture products. In the 11th Five-Year Plan period, Guangxi's farming patterns were outdated, and the application of new farming patterns was not promoted much. Thus, Guangxi's carbon sink declined in 2007. Guangxi is rich in fish farming resources, and its fishery economy's structure and industrial layout are gradually being optimized. Guangxi established the monitoring system of the fishery ecological environment and increased the efforts of artificial breeding and releasing. As a result, the carbon sinks in Guangxi have increased steadily since 2008.

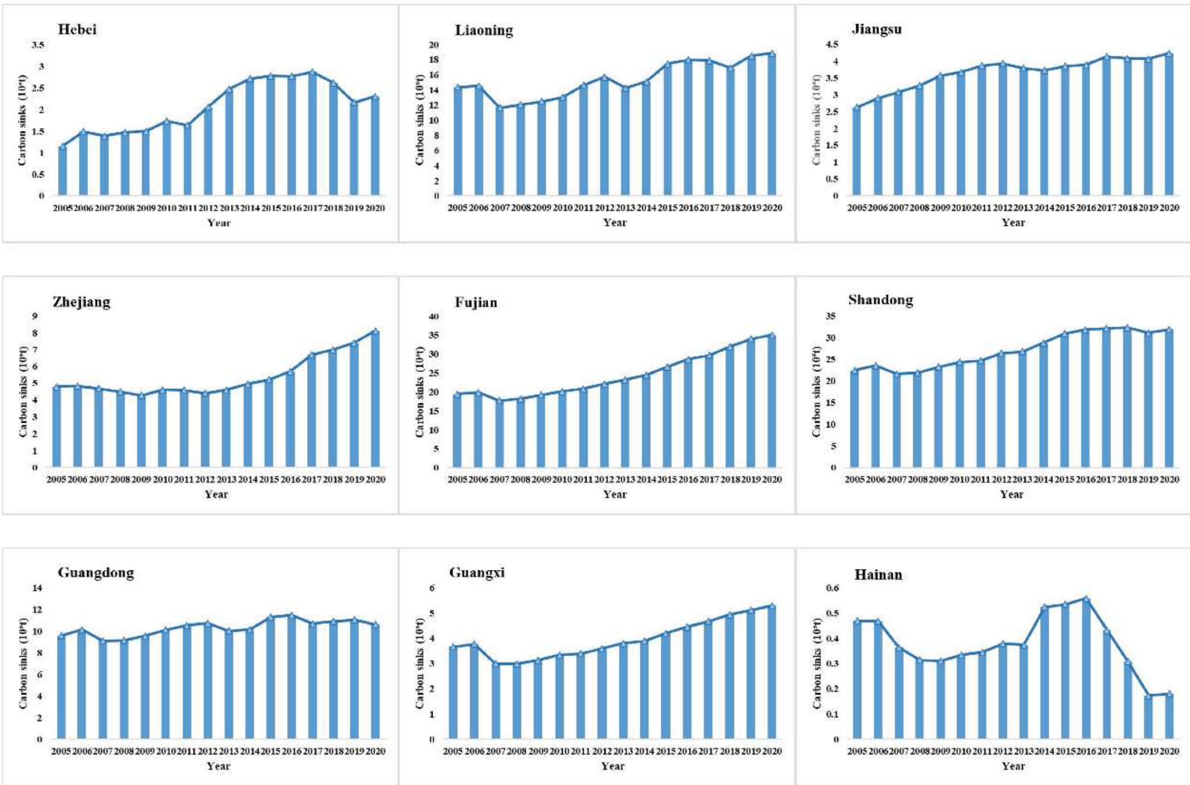

Figure 3. Changes in carbon sinks in coastal provinces from 2005 to 2020.

Jiangsu and Guangdong were the two provinces with insignificant fluctuation trends. Jiangsu built marine pastures offshore, created seaweed farms, and restored marine ecology, increasing the productivity of the sea. It can be seen that from 2006 to 2012, the carbon sinks in Jiangsu were steadily enhanced. However, the accelerated urbanization of Jiangsu has squeezed the development of fisheries, and the trend of increased pollution of waters and the decline of natural resources has not been fundamentally resolved. Jiangsu requires continuous strengthening of its marine living resources conservation efforts. Guangdong's mariculture was at the leading position in China. Guangdong has taken "deep blue fisheries" as the focus of optimizing the structure of the fisheries industry. Moreover, Guangdong has established a "marine industrial zone" focusing on deep-water net tank farming. However, the performance of Guangdong's carbon sinks was unstable and did not achieve a steady rise. In recent years, storm surges and red tide disasters have occurred in the coastal areas of Guangdong, and the government should focus on optimizing the resource environment of Guangdong's fisheries.

It can be observed that the gap between the carbon sinks of each province was gradually widening. For provinces with more carbon sinks but unstable growth, the government should focus on marine environmental protection and promote the sustainable development of shellfish and algae farming. In provinces with low carbon sinks, the government can increase shellfish and algae farming to form more carbon sinks and neutralize the emitted carbon.

4.2.3. Provincial Characteristics of Net Carbon Emissions

Figure 4 shows the changes in net carbon emissions for the nine coastal provinces. Most provinces had positive net carbon emissions and were still far from the goal of carbon neutrality. Shandong performed best and had negative net carbon emissions every year, which indicates that Shandong's marine fisheries have reached the carbon neutral target. As a major marine fisheries province, Shandong has been a national leader in the construction of marine pastures. Shandong vigorously developed the marine engineering manufacturing industry and completed the ship repair base. In the meantime, Shandong's marine fishery products had remarkable structural advantages, with the expansion of the healthy aquaculture industry and technical training of fishermen. Next was Fujian, whose net carbon emissions had been negative since 2018. Fujian had strong marine universities and research institutes and sufficient marine talent resources, which laid a good foundation for the scientific and technological development of its marine fisheries. In the field of marine fishery farming and fishing, Fujian's scientific and technological achievements have produced favorable economic and social benefits and contributed to Fujian's achievement of the carbon neutrality target. Liaoning also reached carbon neutrality in 2005, 2006, 2016, 2017, 2019, and 2020. Liaoning has constantly built innovation platforms in the marine field and increased its talent training efforts, providing strong technical and talent support to reach its carbon neutrality target. The remaining provinces had consistently positive net carbon emissions. The worst performing provinces were Zhejiang and Hainan. The carbon sinks in these two provinces were too small to offset the emissions of CO_2. As a large-scale province of marine fishery resources, Zhejiang had low efficiency in the transformation of scientific and technological achievements. Due to the lack of incentive policies and financial support, it was not easy to promote the achievements of Zhejiang's marine fishery, and new technologies could not be industrialized. Hence, the CO_2 emissions from Zhejiang's marine fishery far exceeded the carbon sink it created. The industrialization level of the marine fishery in Hainan was not high, and the various links of fishery production failed to realize effective links. Hainan's marine science and technology forces were weak, with a lack of talent and scattered research institutions. These factors have affected the impact of the comprehensive advantages of Hainan. Shandong's shellfish and algae aquaculture industries have been developing well and can form excess carbon sinks to absorb CO_2 from the atmosphere. However, China cannot rely on Shandong alone to achieve its goal of carbon neutrality. Other provinces need to effectively use marine ecosystems to absorb CO_2 and achieve long-term carbon storage in the ocean.

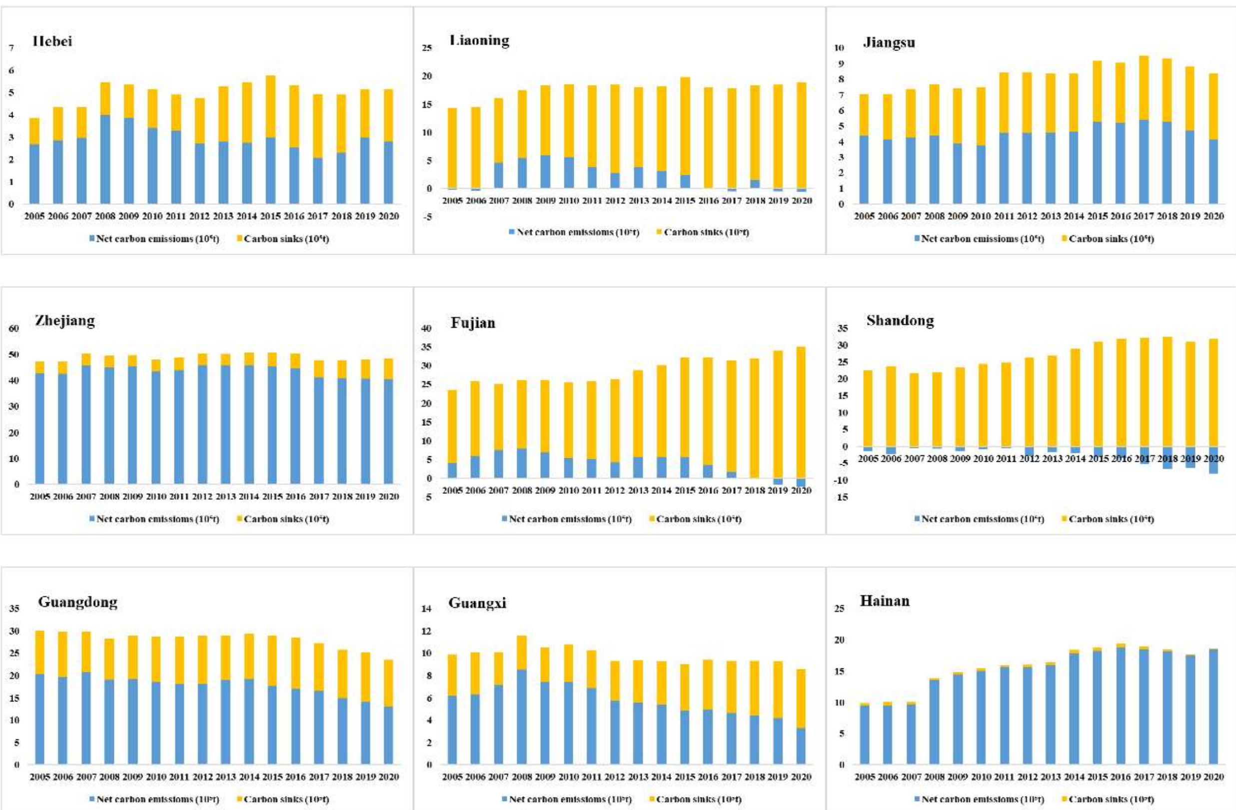

Figure 4. Changes in net carbon emissions in coastal provinces from 2005 to 2020.

4.3. Analysis of Net Carbon Emissions Drivers

Taking 2005 as the base period, the drivers of net carbon emissions from marine fisheries were decomposed by the LMDI model. The year-by-year and cumulative effects of each driving factor were calculated in Table 5. From Table 5, it can be seen that the positive and negative driving effects of net carbon emissions from marine fisheries are relatively uneven, with carbon intensity and industrial structure being the main contributors to net carbon emissions. Carbon intensity purely suppressed net carbon emissions, while industrial structure purely promoted net carbon emissions.

Table 5. LMDI decomposition results in net carbon emissions from marine fisheries in China (10^5 t).

Year	ΔC_{net}		ΔC_{int}		ΔC_{str}		ΔC_{eff}		ΔC_{sca}	
	Yearly	Cumulation	Yearly	Cumulation	Yearly	Cumulation	Yearly	Cumulation	Yearly	Cumulation
2005–2006	0.31	0.31	−7.70	−7.70	9.07	9.07	1.98	1.98	−3.04	−3.04
2006–2007	13.82	14.13	6.86	−0.84	21.51	30.59	−15.77	−13.79	1.22	−1.82
2007–2008	5.36	19.49	−3.98	−4.82	13.77	44.35	−15.35	−29.15	10.93	9.10
2008–2009	−1.46	18.03	−9.43	−14.25	5.30	49.66	1.51	−27.64	1.16	10.26
2009–2010	−4.46	13.56	−18.55	−32.81	11.90	61.55	0.49	−27.14	1.70	11.96
2010–2011	−0.68	12.88	13.06	−19.75	−16.91	44.64	−3.77	−30.91	6.94	18.90
2011–2012	−4.05	8.83	−47.96	−67.71	41.91	86.55	−1.95	−32.86	3.95	22.85
2012–2013	−0.36	8.47	−11.23	−78.94	11.37	97.92	−2.18	−35.04	1.69	24.54
2013–2014	0.98	9.45	−5.31	−84.25	4.96	102.88	2.68	−32.36	−1.36	23.17
2014–2015	1.64	11.09	−1.88	−86.13	0.93	103.82	3.79	−28.57	−1.20	21.97
2015–2016	−5.96	5.14	−9.42	−95.55	2.46	106.28	2.16	−26.41	−1.16	20.81
2016–2017	−9.11	−3.97	−12.14	−107.68	18.62	124.90	−16.06	−42.47	0.47	21.28
2017–2018	−3.31	−7.28	−10.93	−118.61	12.81	137.72	−4.47	−46.94	−0.72	20.56
2018–2019	−5.19	−12.47	−3.61	−122.22	1.80	139.52	−1.31	−48.25	−2.08	18.48
2019–2020	−4.36	−16.83	−8.94	−131.16	8.55	148.07	−0.90	−49.15	−3.07	15.42

Carbon intensity effect (C_{int}): carbon intensity was the main negative driver of net carbon emissions. As the negative driver with the highest cumulative contribution, the increase in carbon intensity played a greater role in restraining net carbon emissions. The year-by-year effect had a higher degree of influence on the changes in net carbon emissions, and all of them were negative. Overall, the negative pull of the carbon intensity effect on net carbon emissions was increasing. This indicates that China's marine fishery development is gradually approaching low carbon development.

Industrial structure effect (C_{str}): industrial structure was the main positive driver of net carbon emissions. The effect was positive for all years except 2011. Specifically, the industrial structure drove the growth of net carbon emissions. In most years, the effect of carbon intensity was stronger than that of industrial structure. This implies that the net carbon emissions promoted by industrial structure could be offset by carbon intensity. The adjustment of the industrial structure did not achieve the expected effect of emission reduction and there is still much space for improvement.

Industrial efficiency effect (C_{eff}): in different years, industrial efficiency had both positive and negative effects on net carbon emissions. The final cumulative contribution of industrial efficiency to net carbon emissions was negative. The negative driving effect of industrial efficiency on net carbon emissions was apparent in 2007, 2008, and 2017. This suggests that the improvement of industrial efficiency was one of the factors that curbed net carbon emissions.

Industrial scale effect (C_{sca}): industrial scale also had both positive and negative effects on net carbon emissions, with a positive contribution most of the time. The contribution of industrial scale to net carbon emissions was more pronounced in 2008 and 2011. From this, it can be assumed that part of the increase in net carbon emissions from marine fisheries was due to the expansion of the industrial scale. This means that it is not desirable to blindly increase the number of employees and that the population should be reduced by an appropriate amount while meeting production needs.

5. Discussion

From Figure 1, it can be seen that the development trend of net carbon emissions of China's marine fisheries was smooth and conformed to the linear change characteristics. So, in this section, a linear function is used to fit its variation pattern and predict whether China's marine fisheries can reach the carbon neutrality target by 2060. Based on the results of the driver analysis in this paper and existing literature references, three independent variables were identified: economic output (X_1), fishing production (X_2), and energy consumption (X_3). According to the fitting results, the trends of marine fisheries' net carbon emissions are as follows:

$$\hat{y} = -1.23X_1 - 13.29X_2 + 28.33X_3 - 89.72 \left(R^2 = 0.95\right) \tag{23}$$

According to the analysis results, when X_1, X_2, and X_3 are the data for the base year 2005, the net carbon emission of China's marine fishery is 8.897 million tons. Based on the actual development of China's marine fishery and the data obtained in this paper, relevant variables are set as follows: the annual growth rates of economic output, fishing production, and energy consumption are 3%, −5%, and 1%, respectively. Estimated by the fitted model, the net carbon emissions from marine fisheries will be 0.118 million tons by 2069. By 2070, the net carbon emissions of marine fisheries will be −0.407 million tons, reaching a carbon neutral state. This result falls short of China's current goal of achieving carbon neutrality by 2060, exceeding it by 10 years. Based on this model, this paper introduces the influence of policy factors. Assuming that China's marine fisheries fully implement the carbon emission trading policy in 2025, it will increase economic output and reduce energy consumption. Therefore, from 2025, the annual growth rates of economic output and energy consumption are set at 3.5% and 0.75%, respectively. Assuming that the marine fishery fully implements the carbon tax policy in 2030, it will further increase economic output and reduce energy consumption. So, from 2030, the annual growth rates of economic output and energy consumption are set at 4% and 0.5%, respectively. According to the data, after the policy is implemented, the net carbon emissions from marine fisheries will be 0.169 million tons by 2047. By 2048, the net carbon emissions of marine fisheries are −0.461 million tons, reaching the carbon neutrality target ahead of schedule. As a result, the emission reduction efforts of marine fisheries still need to take focused policy measures to promote the achievement of the carbon neutrality goal.

Compared to the traditional "removable carbon sink" model [44], excluding the DOC and POC sinks formed during the growth of shellfish and algae would underestimate the carbon sink capacity of marine fisheries by 37.94%. Thus, it is necessary to consider DOC and POC carbon sinks formed by shellfish and algae growth in the calculation model. The results of the carbon sink calculation in this paper are consistent with [7]. The analysis in [14] of the carbon balance trend of China's marine fisheries indicated that China's marine fisheries will not reach carbon balance until 2230. Their calculations of carbon sinks used the "removable carbon sink" model, which underestimated the carbon sinks formed by shellfish and algae farming, so they calculated the time to carbon balance much later. The predictions of the carbon intensity of marine fisheries by [45] also suggested that China's current carbon reduction efforts would not achieve the goal of carbon neutrality by 2060.

The analysis results of the driving factors of net carbon emissions in this paper were similar to those of [13,29]. The result of [29] argued that carbon intensity accelerated carbon reduction, while industrial structure inhibited carbon reduction. In this paper, the results indicated that carbon intensity was a positive driver of net carbon emissions and industrial structure was a negative driver. In addition, the lower the net carbon emissions, the better the carbon reduction. Ma et al.'s study revealed that industrial structure had a negative pull on carbon emissions, but the effect of the industrial scale was mainly negative [46]. Their study of industrial-scale effects was subdivided into the populations of marine capture, fish processing, and aquaculture industries. Among them, the changes in the number of people in marine capture and fish processing mainly determined the direction of the contribution of industrial scale to carbon emissions. Guan also highlighted that carbon emission intensity and farming efficiency played a positive role in net carbon emissions. However, their expressions of carbon emission intensity and farming efficiency were different from this paper. Carbon intensity was the ratio of carbon emissions to shellfish cultivation output. Farming efficiency was the ratio of GOP to the number of people engaged in mariculture. In addition, none of the existing studies has decomposed the drivers of net carbon emissions. This paper complements previous research on marine fisheries by calculating parameters related to net carbon emissions.

6. Conclusions and Policy Suggestions

6.1. Conclusions

Every year, organisms around the world absorb large amounts of carbon through photosynthesis, with marine organisms accounting for 55% of that carbon absorption [47]. Carbon sequestration through marine fisheries is an essential pathway to carbon sink formation. Nevertheless, marine fisheries are also a source of carbon emissions. Therefore, under the carbon neutrality target, it is necessary to dissect whether the net carbon emissions from marine fisheries are neutral or not. Based on the measurement of carbon emissions and carbon sinks from marine fisheries, this paper assessed the net carbon emissions of each province in China. The drivers of net carbon emissions were analyzed through the LMDI model. The contributions of carbon intensity, industrial structure, industrial efficiency, and industrial scale to the level of net carbon emissions in China were investigated. The results provide a theoretical basis for realizing ecological values in marine fisheries. The main conclusions of this paper are as follows:

1. From 2005 to 2020, carbon emissions from China's marine fisheries increased by 12.75%, carbon sinks increased by 48.44%, and net carbon emissions decreased by 19.14%. This result indicated that the pressure on the environment from China's marine fisheries was decreasing but the goal of carbon neutrality was still some way off. The overall trend of carbon emissions was rising and then falling, carbon sinks were on the rise overall, and net carbon emissions were on the decline overall.
2. The results of carbon emission estimation for coastal provinces revealed that only Guangdong and Guangxi showed a decreasing trend in carbon emissions as a whole. The remaining seven provinces saw an increase in carbon emissions; the most significant increase was in Hainan. The fluctuating trend of Zhejiang and Hebei was obvious. Guangdong's carbon emissions were on a steady downward trend, with only one significant increase in the value for Guangxi in 2008. The carbon emissions of Fujian and Hainan were growing stably. The carbon emissions of Liaoning, Jiangsu, and Shandong were also fluctuating, but the fluctuation was not significant. Among the carbon sinks of nine provinces, only Hainan showed a decreasing trend in the whole carbon sink, while the remaining eight provinces had an increase in carbon sinks. Hebei, Liaoning, and Hainan had significant fluctuation trends. The rising trend was more stable in Zhejiang, Fujian, Shandong, and Guangxi. Jiangsu and Guangdong were the two provinces with inconspicuous trends. In the performance of net carbon emissions, Shandong had a negative value every year. Since 2018, Fujian's net carbon emissions have achieved a negative value. Liaoning also achieved carbon neutrality in 2005, 2006, 2016, 2017, 2019, and 2020. The remaining provinces had consistently positive net carbon emissions.
3. In terms of the drivers of net carbon emissions, carbon intensity was the main negative driver and industrial structure was the main positive driver. The effect of industrial efficiency and industrial scale on net carbon emissions were both positive and negative. However, the final cumulative contribution of the industrial efficiency to net carbon emissions was negative and the cumulative contribution of the industrial scale was positive.

6.2. Policy Suggestions

Based on the assessment results of carbon emissions, carbon sinks and net carbon emissions from marine fisheries, and the analysis of the drivers of net carbon emissions, this paper proposes the following policy recommendations:

1. In response to the development status of marine fisheries in different regions, the government should allocate carbon reduction development targets based on local conditions. Local governments can take strategic initiatives that match local ocean carrying capacity. Each province can focus on developing and farming profitable aquatic products to form a unique marine aquaculture system. The government should cultivate and promote ecological farming models with different sea areas and species combinations, and expand the effective space for biological carbon sequestration in coastal areas from different dimensions.
2. It is essential to increase the intensity of carbon taxation policies. A carbon tax means companies pay an environmental cost for the greenhouse gas emissions they generate. The reduction in carbon emissions by a carbon tax is far greater than that of green technology innovation [48]. Marine fishery is a source of carbon emissions. The government can adjust the type of operation of motorized fishing vessels by imposing a carbon tax, thereby reducing carbon emissions from the source.
3. By establishing a compensation mechanism for marine shellfish and algae cultivation, fishermen are encouraged to cultivate production. Shellfish and algae aquaculture not only sequester carbon, but also purify water and release oxygen [14]. Hence, the government should provide some incentives for this production process. Fishermen can enhance shellfish and algae production in marine fisheries without exceeding the carrying capacity of the resource environment. The compensation incentive criteria can refer to the economic and ecological values generated by shellfish and algae cultivation.
4. The government could promote the carbon emission trading policy. This policy can clearly define the carbon emission property rights of each marine fishery enterprise, thereby enabling the optimal allocation of carbon emissions among enterprises at a lower cost. Under the pressure of allowance, companies can be motivated to improve their technology to reduce emissions consciously, and those with more advanced technology will face less pressure for allowance.
5. It is necessary to promote international blue carbon co-operation and trading of marine fisheries. The establishment of blue carbon co-operation and trading mechanism with other countries will increase the implementation of global fishery resources and extend the industrial chain. Extending the industrial chain can increase the market demand for marine shellfish and algae, consequently increasing the carbon sink of marine fisheries.

This paper also has some limitations. The calculation of carbon emissions in this paper only considered the direct carbon emissions from fuel consumption and lacked the calculation of indirect carbon emissions from electricity consumption. Moreover, this paper explored the drivers of net carbon emissions from a national perspective, without differentiating the drivers of coastal provinces. Future research could explore these questions in depth.

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Nomenclature

Symbols	
C	Coal consumption (10^5 t)
C^s	Shell carbon sink (10^5 t)
C^{DOC}	The carbon sink formed by the release of DOC (10^5 t)
C^{POC}	The carbon sink formed by the release of POC (10^5 t)
C_{int}	Carbon intensity
C_{str}	Industrial structure
C_{eff}	Industrial efficiency
C_{sca}	Industrial scale
C_i^{st}	Carbon in shellfish soft tissue (10^5 t)
C_j^a	Algal bodies carbon sink (10^5 t)
C_{net}	Net CO_2 emissions (10^5 t)
E	Employee number
F_C	The amount of carbon per ton of standard coal
G	The economic output value of marine fisheries
h	The fuel oil conversion coefficient of standard coal
i	Shellfish species
j	Algae species
m	Operation modes of fishing boats
P	Main engine power (kw)
P_j^{al}	Algal yield (10^5 t)
P_i^{sh}	Shellfish yield (10^5 t)
Q_c	The amount of carbon (10^5 t)
Q_{co_2}	CO_2 emissions (10^5 t)
Q_E	Effective oxidation fraction
R_i^s	Dry weight ratio of shell (%)
R_i^{st}	Dry weight ratio of soft tissue (%)
t	Year
TC^{al}	Carbon sinks of algae (10^5 t)
$TC^{al}_{CO_2}$	CO_2 sinks of algae (10^5 t)
TC^{sh}	Carbon sinks of shellfish (10^5 t)
$TC^{sh}_{CO_2}$	CO_2 sinks of shellfish (10^5 t)
w_i^s	Carbon content of shell (%)
w_i^{st}	Carbon content of soft tissue (%)
w_j^a	Algal carbon content (%)
Y	Fishing production (10^5 t)
Greek symbols	
α	The share of *POC* released during algal growth in photosynthetic productivity
β	The share of *DOC* released during algal growth in photosynthetic productivity
μ	Oil consumption coefficient (t/kw)
ω	The constant for carbon to CO_2 conversion
γ^{DOC}	Conversion ratio from *DOC* to carbon sinks
γ^{POC}	Conversion ratio from *POC* to carbon sinks
ε	Proportion of carbon in the shell from organic carbon or marine sediment to the total shell carbon
δ	The ratio of CO_2 emitted from fuel oil to coal combustion
Acronym	
DIC	Dissolved inorganic carbon
DOC	Dissolved organic carbon
EC	Excretion carbon

FC	Fecal carbon
GC	Growth carbon
LMDI	Log-mean decomposition index
POC	Particulate organic carbon
RC	Respiration carbon
RDOC	Recalcitrant dissolved organic carbon
TDC	Total dietary carbon

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Have Non-Native English-Speaking Marine Cadet Engineers Been Educated Appropriately?

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Abstract: Freight transport via ships is the cheapest and most effective way to transfer more than 80% of the global cargo volume. Seafarers have always been multinational, and accordingly, non-English-speaking crew members are becoming an increasing presence on board. Although marine engineers comprise half of the crews among all seafarers on board ships, Standard English guides, such as SMCP for navigation officers designed to reduce communication barriers, are unavailable for marine engineers. IMO conventions require marine engineers to possess adequate English skills. However, marine accidents due to inappropriate communication between crew members continue to occur. In this paper, 185 marine engineer cadets enrolled in two universities who had completed 12 months of training on a commercial ship or school training ship were surveyed in terms of the adequacy of English courses for marine engineers in class. This paper investigated whether the marine engineer English subjects are reviewed and analyzed and whether the English examination for the Certificate of Competence is suitable for the content taught in international maritime instruments and for the actual work of engineers. Finally, this paper aimed to establish a need to develop Standard English for engineers.

Keywords: ship; transport; English; engineer; IMO

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1. Introduction

According to the International Marine Organization(IMO), more than 80% of global trade is carried out via ships using international transportation logistics. This delivery method is the cheapest and most efficient and can transport many different types of items at once [1–5]. The United Nations Conference on Trade and Development (UNCTAD) reported that seaborne trade expanded by 2.7% in 2018, which is below the annual average of 3.0%. However, UNCTAD has predicted an annual average growth rate of 3.4% for 2019–2024 [6].

While the shipping industry has been continuously expanding, the leading causes of accidents at sea are human elements [7–10]. Almost 75–96% of marine casualties are caused by human error [11,12]. Human error in maritime accidents is the most important element requiring attention, as Rothblum pointed out [13]. The United States Coast Guard(USCG) studies have shown that human error contributes to 84–88% of tanker accidents, 79% of towing vessel groundings, 89–96% of collisions, 75% of allisions, and 75% of fire and explosions [13]. On merchant ships, 80% of the crew are from different nationalities with different languages [14,15]. Around 66–80% of the world's merchant fleets have multicultural crews [16–18]. According to a report by UNCTAD, Asia is the largest provider of a seafaring workforce in the world, accounting for four of the top five countries supplying seafarers in 2021: The Philippines, Indonesia, China, India, and Russia [19]. English is not the native language of any of these countries. For those multilingual and non-native-speaking crew members on board ships, the Standard Marine Communication Phrases (SMCP) were compiled to aid communication [20]. The 22nd Assembly of the IMO adopted the SMCP in November 2001 [21]. Despite this, it was noted that the skill of seafarers in using English is questionable [22]. Furthermore, IMO instruments such as the Standards of Training, Certification, and Watchkeeping(STCW), Safety of Life at Sea(SOLAS), and the International Convention for the Prevention of Pollution from Ships(MARPOL) require seafarers to be adequately qualified. Throughout the last decade, many accidents due to human error have been reported and recorded, and in most cases, the main reason was a communication misunderstanding [23–29]. A lack of communication has resulted in major marine accidents, and all discussions about possible measures or solutions have concluded with the general belief that in order to prevent such catastrophes and risks, there must be a common language that all seafarers and trainees have to speak fluently [30,31].

To avoid accidents caused by a lack of communication, the shipping industry has regulations relevant to communication between seafarers. For instance, most oil tankers are chartered from shipping companies outside oil interests. Vetting inspections are performed, and one of the goals of such inspections is to check crew members' maritime English knowledge. Therefore, it is essential to mention that all accidents due to miscommunication or language misconception indicate that the English language is not taught to an adequate degree as far as maritime sector professionals are concerned [31]. In order to educate high-quality seafarers in maritime English, instructors should focus on teaching particular terminology and communication skills that include listening, speaking, reading, and writing as required by IMO conventions and the international shipping industry.

The Korean shipping industry has started to employ foreign seafarers to overcome the shortage of skilled ratings. The number of foreign seafarers increased continuously and reached 25,301 (2503 officers and 22,798 ratings) by the end of 2017 [32]. Foreign seafarers account for approximately 40% of seafarers on Korean flagships, and they have increased by 12% every year, while Korean crew members have decreased by 0.5% annually. Multinational crews' communication difficulties and cultural differences can lead to both significant and minor marine incidents. Therefore, there is an urgent need to train and nurture ships' crews to respond to the trend of globalization in the multilingual shipping industry and to meet the mandatory requirements for maritime communication skills and global cultural capabilities on coastal vessels [33].

The aim of this paper is to determine the nature of the lack of English proficiency recognized by non-native English-speaking marine engineer cadets upon first boarding a ship. Thus, first, this paper starts by examining the kinds of English skills that are required according to International Maritime Organization Provisions for marine engineers, and the kinds of tasks that are required in the Convention for Marine Engineers when cadets become engineers. Next, we review the SMCP and the Maritime English Model Course of IMO's requirements for engineers. Based on an analysis of the international conventions and IMO model courses, we analyze what syllabus is used to teach the Engineer Cadet in Maritime English course at two maritime universities in Korea. In addition, this paper examines what kind of content the Maritime English course of the Certificate of Competency(CoC) consists of in marine engineer examinations. Finally, through a survey of engineer cadets who have practiced on board for more than 12 months, we demonstrate what non-native-speaking Korean marine engineer cadets lack in maritime English and areas that they need to improve in.

2. Review of Regulations on International Maritime Instruments

2.1. STCW Convention

There are three levels in the STCW: supportive, operational, and management. The operational level indicates mostly officers in charge of a navigational watch (OICNW) and officers in charge of an engineering watch (OICEW), who are not familiar with on board work compared to those at the management level such as masters and chief mates, chief engineers, and second engineers. As for the STCW convention, the minimum competence for navigational officers on ships of 500 gross tonnage or more at the operational level needs to be qualified for "Use of the IMO Standard Marine Communication Phrases", and they have to use English in written and oral forms in terms of knowledge, understanding, and proficiency. Navigational officers need adequate knowledge of the English language to enable them to use charts and other nautical publications; to understand meteorological information and messages concerning a ship's safety and operation; to communicate with other ships, coast stations, and VTS centers; and to perform their duties with a multilingual crew, including the ability to use and understand the IMO SMCP [20].

Next, chapter III/I, a code of the STCW convention, stipulates requirements about the competence of a marine engineer at the operational level. The minimum competence for officers in charge of an engineer's watch in a manned engine room or a designated duty engineer in a periodically unmanned engine room is that they must be qualified to "use English in written and oral form" to be considered competent. Marine engineers' competence requires adequate knowledge, understanding, and proficiency in English to enable them to use engineering manuals in the written form and to perform their engineering duties in an oral format [34,35].

As stated above, marine engineers at the operational level, such as navigational officers, must be fluent in English in both written and oral forms.

2.2. SOLAS Convention

In accordance with Regulation 8, muster list and emergency instructions of SOLAS chapter III, clear instructions to be followed in the event of an emergency shall be provided for every person on board. In the case of passenger ships, these instructions shall be drawn up in the language or languages required by the ship's flag state and in the English language. Pursuant to Regulation 14, ship's manning of SOLAS chapter V, on ships to which chapter I applies, English shall be used on the bridge as the working language for bridge-to-bridge and bridge-to-shore safety communications as well as for communications on board between the pilot and bridge watchkeeping personnel, unless those directly involved in the communication speak a common language other than English. According to Regulation 30, operational limitations of SOLAS chapter V, this regulation applies to all passenger ships to which chapter I applies. A list of all limitations on the operation of a passenger ship including exemptions from any of these regulations; restrictions in operating areas; weather restrictions; sea state restrictions; restrictions in permissible loads, trim, speed, and any other limitations, whether imposed by the administration or established during the design or the building stages, shall be compiled before the passenger ship is put in service. The list, together with any necessary explanations, shall be documented in a form acceptable to the administration, which shall be kept on board readily available to the master. The list shall be kept updated. If the language used is not English or French, the list shall be provided in one of the two languages. As far as danger messages, Regulation 31 of SOLAS chapter V is concerned, the master of every ship which meets with dangerous ice, a dangerous derelict, or any other direct danger to navigation, or a tropical storm, or encounters sub-freezing air temperatures associated with gale force winds causing severe ice accretion on superstructures, or winds of force 10 or above on the Beaufort scale for which no storm warning has been received, is bound to communicate the information by all means at his disposal to ships in the vicinity, and also to the competent authorities. The form in which the information is sent is not obligatory. It may be transmitted either in plain language (preferably English) or by means of the International Code of Signals. In accordance with Regulation 5, continuous synopsis record of SOLAS chapter XI-1, the continuous synopsis record shall be in the English, French, or Spanish language. Additionally, a translation of the continuous synopsis record into the official language or languages of the administration may be provided [36,37].

2.3. MARPOL Convention

Ships subject to Annex I, Reg. 17 of the MARPOL convention must maintain an engine room oil record book. In this case, in the record book, the contents of receiving fuel oil and lubricants, transporting them on board, outboard discharge through a bilge separator, and maintenance or calibration of the bilge separator must be described in detail in English, French, or Spanish. Annex V, Reg. 10 of the convention also requires a garbage record book to be maintained on vessels. In case of a bunker change between high and low sulfur fuel oil, Annex VI, Reg. 14.6 stipulates strict regulations describing in detail how a fuel oil change should be implemented in the low sulfur limit of the emission control area. Of course, it is also necessary to record, in the engine room logbook, whether the transition to low sulfur took place before entering an Emission Control Area (ECA). Thus, a marine engineer requires English writing skills [38].

2.4. ISM Code

According to Regulation 6 (resource and personnel) of the ISM code, it is necessary to communicate effectively to perform seafarers' duties for the proper implementation of a ship's management system. In this code, ship personnel must be able to communicate with one another in their native language or English to perform their duties. This means that multinational seafarers must possess English reading, writing, speaking, and listening skills [39].

2.5. PSC Procedure

According to Resolution A.1155(32) of the PSC procedure, an engine room logbook is an essential document to be used as official documentary evidence in the case of maritime accidents in court. Information must be recorded accurately and consistently. The Resolution also requires that seafarers on board should have communication skills in their working language and English. In addition, the ship's structural safety evaluation document prepared by the Port State Control Officer (PSCO) must be based on the inspection report conducted for the ship and in their working language and English [40].

Therefore, when the PSCO conducts an engine room inspection, engineers must have English speaking skills to respond to them, just as they need writing skills concerning engine room logbooks. If fire and ship evacuation drills are performed during the PSCO's inspection, special attention is required for any verbal communication problem between the PSCO and non-English-speaking seafarers. The PSC Resolution states that conducting fire and evacuation drills is a crucial aspect of crew competence. In demonstrating the drills, the key issues are how well crews cope in an emergency and how effectively they communicate. If engineer officers have a problem communicating in English, it is clear grounds for remedial action. If there is a communication problem with other crew members on the ship, it is indicated that this is also clear grounds for remedial action.

Moreover, the PSCO procedure requires crew members to be able to understand the information provided in manuals, instructions, and documents relevant to the safe condition and operation of the ship and its equipment. If they are aware of the requirements for maintenance, periodic testing, training and drills, and recording of logbook entries, they have to record this in the related documents. In other words, marine engineer cadets must possess English reading skills to understand manuals and work instructions provided on the ship and to correctly write in engine room logbooks and related documents in English. For instance, all of the Korean shipbuilders, who are making commercial ocean-going ships, supply the manuals in English.

3. IMO SMCP and Model Course

3.1. IMO SMCP

Resolution A.918(22) IMO SMCP is a Standard English rule governing maritime communication [23]. The main contents of this resolution are designed to support the safe navigation of ships and to standardize the English for navigational communication required for sea and port, as well as access between multinational crews. Moreover, the SMCP contains engine matters in the AII/2 chapter regarding standard engine order and B1 1.7~1.13 regarding some machinery operations such as the B1/1.7 briefing on special events; the B1/1.8 briefing on temperatures, pressures, and soundings; the B1/1.9 briefing on the operation of the main engine and auxiliary equipment; the B1/1.10 briefing on pumping of fuel and ballast water; the B1/1.11 briefing on special machinery events and repairs; the B1/1.12 briefing on record keeping; and the B1/1.13 briefing on handing and taking over the watch.

It is questionable whether the Standard English provided by the SMCP provides engineers with enough content to perform all of their duties.

Currently, the Standard English related to marine engineers in the SMCP is only two out of 103 pages of SMCP, from B1/1.7 to B1/1.13. To analyze B1/1.7 to B1/1.13, first, there is no mention of the terminology used in the engine room. One of the important things in communication between seafarers is to use the same terms for the same object. The reason is that there is room for future accidents if different terms are used. The equipment installed in the engine room has to use the same terminology, because most equipment on ships is the same, and the components of each piece of equipment also require the same terminology. Marine engineers on board Japanese owners' ships still use a lot of mixed terms in Japanese and Korean, so on Korean fishing vessels, there are words that are neither Korean nor Japanese, especially in the engine room. Furthermore, although there are multinational crews on board Korean ships, the terms used in the engine room are not Korean, Japanese, or English, and are instead nautical neologisms. There are cases where crews from third countries boarding Korean ships have to learn mixed terms separately [41,42]. In addition to this, B1/1.7~B1/1.13 only deal with briefings of engine work on ships, and do not deal with terms related to the engineer work required by the IMO convention, engine duty watch, or paperwork at all. The SMCP does not deal with this, despite the fact that almost the same number of engineers as navigators are aboard a ship. This means that the English of engineers is just as important as the English of navigation officers in preventing accidents. Of course, the main goal of the SMCP is to deal with English communication between ships, but the SMCP lacks knowledge of many aspects of engineer officers' work, and there is no Standard English textbook for engineer officers.

3.2. Maritime English Model Course 3.17

The IMO Maritime English Model Course 3.17 is the International Maritime Organization's linguistic education guideline for the systematic training and education of various English proficiency elements specified in the STCW convention. In 1999, the first model course was developed with the participation of Marlins and a British maritime publishing company. The first revision was made with the support of the International Shipping Federation (ISF) and the International Maritime Training Trust (IMTT).

In the past, the IMO Maritime English Model Course revised and combined the English curriculum of the former group of maritime engineers (sailors, engineers, etc.) into one. Currently, the guideline for the model course is divided into beginner and intermediate courses according to the learner's language level. Sub-themes related to the work on board a ship are set for each class per level with learning elements of English, grammar, vocabulary, phonetics, and communication skills (listening, reading, writing, and speaking) that are essential for seafarers [35].

On the contrary, in the revised 2015 IMO Maritime English Model Course 3.17, the framework of maritime English education is further divided into general maritime English (GME) and specialized maritime English (SME). GME is the first stage of maritime English education divided into beginner and intermediate courses. In this case, the syllabus is presented step by step. It is designed for the study of English pronunciation, intonation, vocabulary, grammar structure, discourse structure, etc., along with maritime-related topics and scenarios before entering the specialized maritime English learning area.

In terms of instructor qualifications, the IMO Maritime English Model Course 3.17 stipulates the qualifications of the instructors who can implement these model courses in the educational field as follows: "The instructor must be a qualified English instructor trained in the communication approach, content-based teaching method, task-based learning method, etc., and must have a sufficient understanding of the subject of navigation." In other words, as an essential qualification condition, an English instructor must be qualified to effectively convey a wide range of English knowledge such as pronunciation, grammar, intonation, and vocabulary, and knowledge of various teaching methodologies of special-purpose English.

4. Composition and Contents of Marine Engineer English Courses in Maritime Universities in Korea

The basis of the operational level at which engineers should learn English include, at the very least, the STCW convention, the requirements of the SOLAS, MARPOL, ISM Code, PSC procedure, SMCP, and the IMO Model Course 3.17, and practical content necessary for the ship's operation. These rules stipulate that engineers should be equipped with English speaking, listening, writing, and reading skills. This section examines whether students at maritime universities who are completing a course following the STCW convention receive an appropriate education.

Table 1 shows the weekly training contents that students of the Korea Maritime and Ocean University and the Mokpo National Maritime University take in courses related to marine engineer English. These two universities were examined because they produce 500 out of 600 Korean third-class engineers every year. Thus, by examining the institutional English curriculum of these universities, it was judged that the actual condition of English education for engineers in Korea could be confirmed.

Table 1. Training contents of marine engineer English.

Week	Korea Maritime and Ocean University	Mokpo National Maritime University
1	Introduction to the Course Self-Introduction Personal Proposal	Fundamental Marine Engineering Terminology
2	Business Letter General Report General Communication Report	Compositions of English Sentence
3	Engine Logbook, including the officer's duties Abstract Log Accident Report	Diesel Engine
4	Oil Record Book Garbage Record Report Docking Indent Various Accounts	Steam Turbine
5	Main Engine Boiler and Turbine	Boiler
6	Auxiliary Machinery Electric and Electronic Device	Main Propulsion
7	IACS	Mid-Term Examination
8	Mid-Term Examination	Electrical Devices
9	Marine Engineering SMCP	Measurement Devices
10	Marine Engineering SMCP	Auxiliary Machines 1
11	SOLAS	Auxiliary Machines 2
12	MARPOL	Safety
13	STCW	Workshop
14	Other Convention and Codes	Engine Logbook
15	Practical Conversation for Marine Engineers	Navigation
16	Final Examination	Final Examination

4.1. English of the Korea Maritime and Ocean University

The 15-week curriculum consists of a minimum agreement with the conventions or four practical skills in English: 27% (four weeks) for speaking and listening skills; 20% (three weeks) concentrated on preparing various documents necessary for marine engineers during a ship's operation; and 27% (four weeks) for reading ability, with institutional manuals, for example, being allocated. In the case of learning conventions and terminology, four weeks (27%) are allocated. Regarding the three conventions, since students are taught in the subjects of the International Maritime Convention, it can be seen that they overlap in terms of knowledge and terminology.

Moreover, Korea Maritime and Ocean University students are finally assessed on whether they have achieved the sufficient ability required in Model Course 3.17, General English, by receiving a specified minimum score on the Test of English for International Communication (TOEIC), comprising only reading and listening. This work must be principally carried out by acknowledging that learning the entire engineer English content within the 15-week course is impossible.

4.2. English of the Mokpo National Maritime University

The English sentence composition class appears to have been planned using the general education in the English language required in Model Course 3.17. Under the principle that the 15 weeks of lectures should be evenly distributed to develop four English skills, the first and second weeks can be considered to correspond to all four skills in terms of learning general English. A total of 10 weeks are allotted to reading engine room manuals and publications. In other words, 67% of the focus is on reading ability. Only one week is allocated to the recording books prepared in the engine room and general sailing, respectively. Therefore, it is advantageous to allocate time to reading ability for 10 weeks, general English composition (week 2), and basic institutional terminology (week 1). However, there seems to be insufficient time for writing and speaking skills.

Furthermore, the students' English ability achievement is assessed through the TOEIC, as with the Korea Maritime University.

4.3. English of the Marine Engineer Examination for the CoC

The English subjects of the marine engineer examination on the Certificate of Competence (CoC) are marine engineer English and general maritime English. The percentages of these two sub-subjects are 40% and 60%, respectively. General maritime English deals mainly with IMO provisions, not the general issues of ship operation. Marine engineer English covers the principle or theoretical contents of main engine, auxiliary machinery, and electrical and electronic control on board a ship.

The examination of navigation officers for the CoC in Korea also consists of five subjects, one of which is an English test. The English examination consists of two parts, the SMCP and general maritime English, at a ratio of 40% to 60%, respectively. The SMCP component comprises a multiple-choice test (with four options for each question), and general maritime English is related to all aspects of navigation and ship operations necessary for navigators that the SMCP does not cover. It covers general issues necessary for a ship's operation.

Consequently, there is a gap in the meaning of general maritime English between navigators and engineers in the examination for the CoC. The English subject for navigation officers and marine engineers does not fully include the oral form or listening and speaking tests required by each convention. In addition, it does not address the English writing skills required by the above convention.

5. Methodology

5.1. Design of Questionnaire Contents to the Survey

This survey was designed to find out whether non-native English-speaking marine engineers were adequately receiving maritime English education. The questionnaires had been designed and developed by two ex-2nd class engineers, one university professor, and one doctoral researcher in measurement and evaluation major. The completed questionnaire was delivered to the respondents through the application platform.

The survey was conducted with the questions in Korean, as shown in Tables 2–4, for Korea Maritime University and Mokpo National Maritime University students entering the fourth year of engineering within the next year. The content and composition of this survey was designed to recognize which English skills marine engineer cadets lack during their 12-month training period on a ship, and to know what English skills need to be supplemented in preparation for boarding as a ship engineer in the future.

Table 2. Questions to assess the background of marine engineers' English skill.

	Questions	1	2	3	4	5
1	Do you know if the maritime engineer English for the examination of marine engineers is currently organized as follows? (1) Engineering English: Read the marine engineering manual; (2) maritime English: IMO Convention	15.4	45.1	25.3	11.5	2.7
2	Do you know if the STCW Convention requires the ability to read and write marine engineering manuals and publications as a marine engineering English subject?	15.9	44	25.3	13.2	1.6
3	Do you know if the STCW Convention requires that the English proficiency of an engineer includes listening and speaking ability necessary for communication while on duty?	18.7	49.5	22	8.2	1.6
4	In connection with communication with foreign seafarers on board a ship, have you experienced many difficulties in communication due to your lack of English skills?	4.4	15.4	44.5	20.9	14.8
5	Have you ever thought that your English expression was a problem in the event of a near-miss while working with foreign seafarers?	2.2	5.5	35.2	32.4	24.7
6	The Republic of Korea has mutual recognition agreements of the CoC with 31 countries, including the UK. Are you willing to board a foreign vessel if you have sufficient English proficiency?	45.1	31.3	18.1	4.4	1.1
7	There is a standard maritime English communication set by the International Maritime Organization (IMO). For navigation officers, except for marine engineers, there is no standardized or customized marine engineering English set by the IMO.Do you think the development of standardized marine engineering English is now necessary?	23.6	46.2	27.5	27.5	0
8	Do you think that the number of accidents related to machinery would be reduced if standardized marine engineering English is provided to the engineers as well?	14.8	37.4	33	12.6	2.2
9	Do you think the marine engineering English subject for the CoC is necessary in the maritime engineer exam?	23.1	50.5	22.5	3.3	0.5
10	Do you think the test method of the marine engineering English subject should be improved in a more practical way?	23.1	48.4	25.3	2.7	0.5
11	Do you think the proportion of marine engineering English of the CoC should be increased over other subjects?	12.6	29.7	41.8	14.3	1.6
12	The marine engineering English subjects of the existing CoC test consist of reading questions and finding answers (reading-oriented). Do you think that the addition of listening and speaking assessments in the marine engineering English subject in accordance with the STCW Convention will help you work with machinery?	18.7	40.7	29.1	7.7	3.8

1 = Strongly Agree; 2 = Agree; 3 = Neutral; 4 = Disagree; 5 = Strongly Disagree.

Table 3. Questions about the minimum necessary English proficiency in ship operation.

	Questions	Very Low	Low	More or Less	High	Very High
1	How much English reading skills are required for ship operation works?	0	2.7	34.1	49.5	13.7
2	How much English writing skills are required for ship operation works?	0	11.5	51.1	31.3	6
3	How much English-speaking skills are required for ship operation works?	0.5	1.6	16.5	47.3	34.1
4	How much English listening skills are required for ship operation works?	0	1.1	19.8	45.6	33.5

Table 4. Questions about what personal English ability is necessary for confident ship operation.

	Questions	Reading	Writing	Speaking	Listening
1	What aspect of speaking English on ship operation works are you most confident about?	48.4	8.8	17	25.8
2	What aspect of your ability to speak English on ship operation works are you least confident about?	4.4	27.5	52.2	15.9
3	In your experience on board a ship, what is the most vital aspect of English proficiency in terms of engine room operation and management?	8.8	4.4	54.9	31.9

5.2. Information on the Respondents

This study analyzed data on 185 students from two marine-specialized universities located in Korea. Among all the respondents, those who did not respond or whose response values were outside the mean of ±3 standard deviations were removed. The personal background characteristics of the respondents are shown in Table 5. All marine engineer cadets completed a 12-month training period, whether on a university training ship and/or commissioned training through a shipping company. The gender distribution of the respondents was 154 men (83.2%) and 31 women (16.8%). The period of school boarding training was 10 (5.4%) at 0 months, 147 (79.5%) at 6 months, and 28 (15.1%) at 12 months. In total, 121 (65.4%) respondents, who have experience with foreign seafarers, were surveyed. The responded number of working with foreign seafarers was 63 (34.1%) of between 10 and 14 foreign seafarers, which was the most; with 31 (16.8%) of less than 10 foreign seafarers; and 27 (14.6%) of 15 or more foreign seafarers. By nationality of the foreign seafarers, the Philippines had the most with 80 (52.3%), followed by Myanmar with 34 (22.2%), Indonesia with 14 (9.2%), India with 10 (6.5%), and Georgia with 7 (4.6%).

5.3. Analysis

The survey was analyzed through SPSS. The survey tool used self-developed questions to investigate the opinions of using English as a marine engineer, such as whether or not they experienced communication problems due to the inappropriate use of English with crew members from other countries as per Tables 2–4. The questions used in this study were: recognition of the composition and content of the marine engineer English curriculum (3 questions), the ability to use English for work on a ship (2 questions), the necessity to develop standard marine engineer English (2 questions), and engine room work. It consisted of English proficiency most necessary for operation and management (4 questions), the necessity for each area of using English for ship work (4 questions), and the necessity for the marine engineer English subject in the CoC examination (4 questions). The experience of experiencing inconvenience in communicating with foreign crew members, problems with English expression in the event of a near-miss or an accident, and intention to board foreign ships were additionally investigated if English proficiency was sufficient. All questions excluding qualitative variables were composed of a five-point Likert scale among the total questions. The reliability of each sub-item is shown in Table 6.

Table 5. The respondents' personal background characteristics (n = 185).

Category		Frequency	Percentage
Sex	Male	154	83.2
	Female	31	16.8
Period of experience on board a training ship in school	0 months	10	5.4
	Less than 6 months	147	79.5
	6 months or more	28	5.1
Experience with foreign seafarers	Yes	121	65.4
	No	64	34.6
Number of foreign seafarers	0 persons	64	34.6
	Fewer than 10 persons	31	16.8
	Between 10 and 14 persons	63	34.1
	More than 15 persons	27	14.6
Nationality	Philippines	80	52.3
	Myanmar	34	22.2
	Indonesia	14	9.2
	India	10	6.5
	Georgia	7	4.6
	China	2	1.3
	Latvia	2	1.3
	Russia	1	0.7
	Cambodia	1	0.7
	Vietnam	1	0.7
	Croatia	1	0.7
Total		185	100

Table 6. Cronbach's alpha coefficient.

Sub-Questions	Question Number	Number of Questions	Cronbach's α
Recognition of marine engineer English (Engineer English awareness)	Table 2 (1, 2, 3)	3	0.83
Necessity for the development of standard marine engineer English (Requiring standard English)	Table 2 (7, 8)	2	0.72
Importance of each ability in ship maintenance and operation (Need for business English)	Table 4 (3 questions)	3	0.71
Importance in the marine engineer examination (Need for marine engineer English)	Table 2 (9, 10, 11, 12)	4	0.80
Total		12	0.84

In order to determine what kind of correlation exists between communication discomfort frequency, communication problems in the event of a near-miss or an accident, and intention to board a foreign shipping company, the product moment correlation coefficient of Pearson was calculated, and the statistical significance was tested. The product moment correlation coefficient of Pearson is a measure of the linear relationship between two questions/measures/variables, X and Y. The correlation value can range from +1 to −1. A positive correlation means there is a positive relationship between two questions. A negative correlation means there is a relationship between two questions that moves in the opposite direction. A correlation of 0 means that there is no linear relationship between two questions; although, there could be a non-linear relationship between two questions. The Pearson correlation coefficient is the most common and widely used measure of the degree of linear relationship between two variables. It should be noted that the Pearson moment correlation tells us whether there is a linear relationship between two variables, but it does not tell us anything about causality. For the 121 respondents who had experience on board with foreign seafarers, the part of using English on the ship about which they were most comfortable was divided into three groups (reading and writing, speaking, and listening), making communication difficult due to a lack of English proficiency. A one-way analysis of variance (ANOVA) was conducted to determine whether there was any difference between the experience of uncomfortable communication with foreign seafarers, the degree of thinking that it was a problem in terms of English expression when a near-miss or an accident occurred during work with foreign seafarers, and the intention to board a foreign ship.

6. Results and Discussion

Correlation between Awareness, Importance, and Necessity for Marine Engineer English and Communication Factors on Board a Ship

Table 7 shows the correlations between awareness, importance, and necessity of marine engineer English communication factors on board a ship. Further, questions 4–6 in Table 2 regarding discomfort communication, accident by miscommunication, and intentions for boarding foreign ships are added for the correlation analysis.

Table 7. Correlation between recognition marine engineer English, necessity for marine English use, communication, etc. (n = 121).

	Engineer English Awareness	Requiring Standard English	Need for Business English	Need for Marine Engineer English	Discomfort for Communication	Accident by Miscommunication	Intentions for Boarding Foreign Ships
Engineer English awareness	1						
Requiring standard English	0.358 **	1					
Need for business English	0.111	0.120	1				
Need for marine engineer English	0.410 **	0.478 **	0.359 **	1			
Discomfort of communication	−0.192 *	−0.051	0.173	−0.097	1		
Accident by miscommunication	0.027	0.204 *	0.069	0.121	0.181 *	1	
Intentions for boarding foreign ships	0.088	0.138	0.030	0.179 *	−0.207 *	−0.201 *	1

* $p < 0.05$, ** $p < 0.01$.

Recognition of the composition and content of marine engineer English subjects was distinctly positive, correlated with the necessity for the marine engineer English subject of the maritime engineer examination for the CoC, with r = +0.41. The necessity for engineer standard English development was r = +0.36 with a distinctly positive correlation. However, there was a negative correlation of r = −0.19 in the case of experiencing discomfort in communication with foreign seafarers. It can be seen that the higher the awareness of the composition and contents of the marine engineer English subject, the less frequent the inconvenience of communication with foreign seafarers. The necessity for the development of standard marine engineer English was distinct positive correlated with the need to improve English for the maritime engineer examination for the CoC, with r = +0.48, and the accident frequency caused by communication problems with foreign seafarers, with r = +0.20. It is possible that the higher the frequency of communication problems with foreign seafarers in the event of an accident, the greater the need to develop a standard marine engineer English. The importance of using English in ship maintenance and operation showed a distinct positive correlation with the necessity for improving the English subject of the maritime engineer examination for the CoC, with r = +0.36. The necessity for improving the English subject of the maritime engineer examination for the CoC showed a weak positive correlation with embarking on a foreign vessel, with r = +0.18. It can be seen that the more the respondents were willing to board a foreign vessel, the greater the need to improve the marine engineer English subject and increase the proportion of marine engineer English subjects. There was a weak positive correlation between the frequency of communication problems with foreign seafarers and the frequency of communication problems with foreign seafarers in the event of a near-miss or an accident, with $r = +0.18$. This means that the higher the frequency of uncomfortable communication with foreign seafarers in English, the higher the frequency of communication in English expressions in the case of an accident. As a result, differences in communication with foreign seafarers by English proficiency in engine room work are shown in Table 8; the group with confidence in listening had the highest communication discomfort (M = 3.17, SD = 1.12). The group with confidence in speaking had the lowest frequency (M = 2.24, SD = 0.95) of communication discomfort. There was a significant difference in the degree of communication discomfort due to a lack of English proficiency in the four groups ($F = 6.99$, $p < 0.01$). When a near-miss or an accident occurred while working with foreign seafarers, the average student of the reading and writing groups thought that English expression was the greatest problem (M = 2.26, SD = 0.90). The group with confidence in listening was the lowest (M = 2.03, SD = 1.1). However, there was no significant difference between the three groups. If English proficiency was sufficient, the average of the speaking group was the highest in terms of whether they were willing to board a foreign ship (M = 4.34, SD = 0.81). Nevertheless, there was no statistically significant difference between the three groups.

Table 8. Differences in communication by proficiency in English.

Category	**Group**			***F***
	Reading and Writing (n = 62)	**Speaking (n = 29)**	**Listening (n = 30)**	
Communication discomfort with foreign seafarers	2.94 (0.97)	2.24 (0.95)	3.17 (1.12)	6.99 **
An accident due to insufficient/inadequate communication in English	2.26 (0.90)	2.07 (0.99)	2.03 (1.1)	0.68
Intention to board a foreign ship	4.15 (0.90)	4.34 (0.81)	4.03 (0.96)	0.92

** $p < 0.01$.

As a result of the need for the development of standard marine engineer English according to the experience of boarding with foreign seafarers, Table 9 shows the results of analyzing the differences in the awareness in terms of composition and content of the marine engineer English courses, the necessity for developing standard marine engineer English, the necessity for improving the English subject of the maritime engineer examination for the CoC, and the importance of using English in the engine room work, depending on whether they had experience on board with foreign seafarers.

The group (n = 121) with experience on board with foreign seafarers showed a higher average than the group with no experience (n = 64) in terms of the three categories, i.e., the composition and content of the marine engineer English subject, the need to develop standard marine engineer English, and the necessity for improving the English subject of the maritime engineer examination. In particular, there was a statistically significant difference between the two groups in the necessity for improving the English subject of the marine Engineer examination ($t = 1.94$, $p < 0.05$). The group with no experience on board with foreign seafarers thought that the use of English for reading and writing is essential for working in the engine room. However, the other group thought that speaking and listening in English are essential. The average of the group with experience on board with foreign seafarers was higher than the other. On the importance of speaking, the group with experience on board with foreign seafarers (M = 4.22, SD = 0.65) was statistically more significant than the other group (M = 3.95, SD = 0.95) and significantly higher ($t = 2.04$, $p < 0.05$). On the necessity and importance of listening ability, the group with experience on board with foreign seafarers (M = 4.23, SD = 0.69) was more statistically significant than the other group (M = 3.91, SD = 0.81) and significantly higher ($t = 2.86$, $p < 0.01$). With respect to the importance of marine engineer English according to the number of foreign seafarers on board together, Table 10 shows the results of analyzing the differences in seven categories.

The group that experienced 11 or more foreign seafarers on board together ($n = 62$) showed a higher average than the group with fewer than 11 foreign seafarers ($n = 59$). The average number of crew members on the ship the students boarded was about 20 persons, so we used 11 persons as the standard when the number of foreign crews was 50% of the total number of crew members.

Table 9. Differences in the necessity for developing marine engineer English according to the presence or absence of experience boarding with foreign seafarers.

Category	Experience on Board with Foreign Seafarers		t
	Presence (n = 121)	Absence (n = 64)	
Awareness of the composition and content of marine engineer English courses	3.66 (0.79)	3.62 (0.88)	0.28
The necessity for developing standard marine engineer English	3.73 (0.80)	3.69 (0.74)	0.36
Need to improve the English subject of maritime engineer examination	3.78 (0.68)	3.57 (0.73)	1.94 *
Reading proficiency for engine room work	3.69 (0.73)	3.81 (0.71)	–1.06
Writing proficiency for engine room work	3.30 (0.81)	3.38 (0.63)	–0.72
Speaking proficiency for engine room work	4.22 (0.65)	3.95 (0.95)	2.04 *
Listening proficiency for engine room work	4.23 (0.69)	3.91 (0.81)	2.86 **

* $p < 0.05$, ** $p < 0.01$.

Table 10. Differences in the necessity for developing institutional English according to the number of foreign seafarers on board together.

Category	Number of Foreign Seafarers on Board Together		t
	Fewer Than 11 People (n = 59)	11 or More People (n = 62)	
Awareness of the composition and content of the marine engineer English courses	3.49 (0.77)	3.82 (0.78)	−2.34 *
The necessity for developing standard marine engineer English	3.65 (0.83)	3.81 (0.78)	−1.06
Need to improve the English subject of the maritime engineer examination	3.77 (0.69)	3.79 (0.67)	−0.19
Reading proficiency for engine room work	3.61 (0.67)	3.77 (0.78)	−1.24
Writing proficiency for engine room work	3.32 (0.78)	3.27 (0.85)	0.32
Speaking proficiency for engine room work	4.12 (0.65)	4.32 (0.65)	−1.74
Listening proficiency for engine room work	4.20 (0.64)	4.26 (0.75)	−0.43

* $p < 0.05$.

In particular, for the group with experience of 11 or more foreign seafarers (M = 3.82, SD = 0.78), the awareness of the marine engineer English subject was statistically significantly different ($t = –2.34$, $p < 0.05$) to that of the other group (M = 3.49, SD = 0.77). On the importance of writing ability for working in the engine room, the group with experience of fewer than 10 foreign seafarers (M = 3.32, SD = 0.78) was not significantly different from the other group (M = 3.27, SD = 0.85). In addition, on the necessity for the three abilities of reading, speaking, and listening, the average of the group with experience with more than 10 foreign seafarers was higher than that of the other group. However, there was no statistically significant difference.

7. Conclusions and Recommendations

In this study, while global cargo volume is transported between continents by ships, crews operating on the ships play a very important role. Ships' crews are becoming multinational, and the ship accidents that occur might be fatal due to communication problems between engineers or with other departments on board. Ship personnel can be divided into two groups: navigators and engineers. In the case of navigation officers, standard maritime English (called the SMCP) is applied, and efforts are being made to reduce accidents caused by human factors. However, the Standard English relating to engine officers in the SMCP covers only a small portion and deals with only general English skills, not the specific terminology used in the engine room, as described in other IMO model courses. IMO conventions such as the STCW, SOLAS, MARPOL, ISM Code, and PSC procedure require a lot of special-purpose English for engineers. However, there is no textbook that can be treated as a standard for engineers in IMO, such as the SMCP for navigation officers, in terms of its content.

Furthermore, there is no English textbook for engineers that covers listening, speaking, writing, and reading skills, which are important in English proficiency. Therefore, in this research, the contents of the institutional English of two representative maritime universities in Korea, which is a non-English-speaking country, were examined. This analysis was also meaningful as only the principles and operation of the IMO conventions and engine room machinery were dealt with in the English course for marine engineers, and only reading-oriented content was taught. IMO regulations or the contents required in the actual engine room were not covered in the universities' lectures, but IMO conventions and engine room machinery were dealt with; only the above two English subjects were dealt with in the Korean naval officer exam. In fact, IMO conventions and engine room machinery are sufficiently dealt with in other subjects for engineers, and the engineers' English course is learned by translating the content of other subjects into English only. It is duplicated with other subjects. In order to prove the validity of this study, a survey was conducted with 185 students who had completed a 12-month boarding at the two universities to see if the engineer's English course they had undertaken at the university was appropriate. The students experienced inconvenience in communication due to a lack of speaking and listening during boarding practice. In addition, the students on board with 10 or more foreigners felt the need for the development of Standard English for engineers.

As a result of this research, the following suggestions are made.

First, an international standard of marine engineer English, suitable for engineers, should be developed in the future. This standard should include the stipulations of the SOLAS, STCW, MARPOL, ISM Code, etc., and the guidance used by actual engineers on ships.

Second, in the Korean engineer's examination system, the definition of general English should be consistent with both navigation and engineer officers. The general English content for engineers is currently dealt with as IMO conventions, but it will have to be converted to English as necessary for vessel operation.

Third, it is necessary to reorganize the exam system for the CoC for Korean engineers, so that listening, speaking, writing, and reading contents are modified altogether.

Fourth, the curriculum of the English subject should be revised so that lectures at Korean universities can test students' abilities as competent engineers in the field.

Lastly, it will be necessary to create an institutional English instructor or designer course so that the engineer's English course can be established and recognized internationally.

This paper has some limitations. First, this paper conducted a survey on non-native speakers who were marine engineers, but the subject was only Korean. If possible, in the future, we think that more valid results can be obtained by conducting a survey targeting multinational non-native speakers, including those from China, Indonesia, etc. Second, the survey was not conducted with the fourth, third, second, and chief engineers working on ships. If these engineers were targeted, more effective results could have been obtained.

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Craft Product Export Promotion Competitiveness: The Mediating Effect between Niche Differentiation Strategy and Export Performance

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Abstract: Export competitiveness is an important factor for national development and economic growth. The craft product market is one of the commodities with high growing value. Thus, many craft product companies are encouraged to export their products to foreign markets. This study aims to examine the strategies and competitiveness of exporting craft products. The sample of 400 respondents who completed the questionnaires represents people working in craft product export companies using marine transport in Thailand. The data analysis was conducted using structural equation modelling (SEM). The findings show that the niche differentiation strategy of craft products positively relates to export promotion competitiveness. Moreover, a niche differentiation strategy positively affects export performance. The results indicate that export promotion competitiveness partially mediates the relationship between niche differentiation strategy and export performance. This study contributes to the craft product export business using marine transport and helps the companies to improve their competitiveness and export performance.

Keywords: export competitiveness; niche differentiation strategy; export performance; marine transportation; craft product

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1. Introduction

Craft products are important for many countries' economies and have been promoted to access the international market [1]. For example, craft products based on functional and cultural importance in the Eastern Cape Province of South Africa have promoted trade development [2]. In addition, small craft producers in South Africa use marketing strategies to promote trades [3]. Craft products in Thailand are well known and important to the Thai economy, can create jobs and career development for people in villages and develop local competency [4]. The craft product industry in Thailand is ranked in the top ten among developing economies [5,6]. The craft product category is valued at THB 30.83 billion (approximately USD 78 million). Well-known Thai craft products include clothes, jewelry, dressing accessories, and leathers. However, the Thai craft product industry encounters many crucial issues, including market knowledge, technology development for local companies, investment ability, product design, development, and an appropriate business strategy. Thus, various studies have attempted to identify factors and strategies to improve the craft product industry. For example, Krasae-in [7] studied consumers' ideas to improve product development for a handicraft business in Thailand. Meanwhile, Kawkamsue and Kritsanaphan [8] looked at crafting latex-coated fabrics with local materials in southern Thailand in order to find new ways to create added value. Another example is the study carried out by Suntrayuth [9] related to creative craft product design and development. However, this study focused only on an appropriate strategy for craft product export companies to improve export performance. The study emphasized domestic companies but did not take into account international companies.

The term "business strategy" is well known for increasing business competitiveness. Porter [10] classified business strategy into three main categories: product differentiation, cost leadership, and focus or niche market. Product differentiation aims to create product uniqueness and be specified or customized for the target market. Wang [11] revealed that product differentiation could link business economics, environmental, and social sustainability issues. Meanwhile, cost leadership provides the benefits of having a low cost of production, which can lead to low prices or a competitive product effort for the customers and gain business performance and profitability [12]. The last type of business strategy is focus or niche strategy, which refers to the use of specified needs from the customers as the main consideration to provide product satisfaction [13,14]. The niche strategy can apply with cost competitiveness and differentiation to become a low-cost niche and niche differentiation strategy [10]. Cannatelli et al. [14] describe how companies pursue niche strategies using brand management. For example, good communication with internal and external customers can link to product quality and company performance. In order to create an appropriate niche differentiation strategy, Maulina [15] suggests that a SWOT analysis should be used when developing a strategy. In addition, Chang [16,17] suggests making improvements in traditional and innovative craft products in Taiwan to gain business competitiveness.

Much research has studied export competitiveness, especially export promotion competitiveness. Geldres-Weiss [18] revealed the effect of export promotion programs (EPPs) on Chilean companies' export activity during trade shows and trade missions. Freixanet and Churakova [19] studied the impact of export promotion programs on companies' export competencies and performance in a transition economy in Russia. The author found that awareness, use, the perception of usefulness, and different intermediate export marketing play a significant role in companies' export competencies and performance. Herewith, export promotion refers to the way to foster the potential to export products to other countries [20]. Export promotion can be government and related agencies' information provision, accessible investment budget and interest for small enterprises, marketing consultancy, law, and policies [17–22]. Competitive export promotion leads to successful business performance from financial and non-financial perspectives, such as market reputation, profitability, customer satisfaction, and internal business improvement [19,22]. However, the existing literature shows limited studies on the competitiveness of export promotion of craft products which link significantly to establish exporting business success.

For the export of products, one of the important transport modes is marine transport. Marine transport is widely explored in the literature, and many articles on a variety of maritime transport-related issues have been published in recent decades [23]. Marine transport encompasses a vast array of operations and, in conjunction with port activities and logistic hubs, has a significant influence on the growth of the maritime industry and commerce. Hence, it fosters economic expansion and job creation [24]. In Malaysia, the marine industry contributes significantly to the local economy, accounting for 40% of GDP. The industry also facilitates other sectors, such as transportation, tourism, shipbuilding and ship repair, and port services [25]. At the same time, most of New Zealand's exporters export their products via maritime transport, accounting for 99.5% of the country's total export volume [26]. It is known that the marine transport mode is vital for Thailand since more than 2800 km of coastline can be found in Thailand. On each side of the country lie bodies of water, including the Gulf of Thailand, a part of the South China Sea, and the Andaman Sea, a part of the Indian Ocean [27].

In creating service quality in maritime transport, Thai [28] revealed six-dimensional constructs comprised of resources, outcomes, process, management, image, and social responsibility (ROPMIS). In addition, the criteria pertaining to the results and processes of service delivery and management aspects are centered on customer satisfaction, which obtained high rankings. Process and management-related issues comprise the core of all quality management systems (i.e., the human element). Agatić and Kolanović [29] stated that maritime transport's service quality includes reliability, adaptability, security, infrastructure, superstructure based on digital technology, and digital talents. Digital technologies used in different parts of seaport operations include logistics infrastructure, freight handling, intermodal transportation, customs clearance, data collection, transport safety and security, energy concerns, and environmental issues. There are many digital technologies that seaports can use. Companies will choose such technologies based on their operations and goals.

As maritime transport is the most important and most used mode of transport compared to other modes of transport, as well as having low transportation costs and the ability to transport large quantities of goods at a time, most craft products are transported by sea [30]. Gu and Gu [31] suggested that the convenience of maritime transportation was the favorable factor for the expansion of the export of handicraft products. Craft products exported through maritime transport can include both expensive things such as silk and cheaper ones [32,33]. Craft products to be transported have to be packed in containers and the containers are loaded onto a container ship which is specially designed, according to Haralambides [34]. Successful handicraft exportation via maritime transportation requires the involvement of many associations such as banking institutions and shipping agencies in the exporting country [35].

Consequently, this research analyzes the impact of niche differentiation strategy on export competitiveness, which is export promotion competitiveness. The study also examines the influences of niche differentiation strategy on export performance. Additionally, this study investigates the effect of export promotion on the relation between niche differentiation strategy and export performance. The findings of this study contribute to the craft product export business using marine transport and help companies improve their export performance. The paper is structured as follows: the introduction section describes the research background and research objectives; Section 2 presents the material and research methods, while Section 3 provides analysis results and discussion. The last section presents the conclusion, research contribution, and suggestions for future research.

2. Materials and Methods

2.1. Research Materials

2.1.1. Niche Differentiation Strategy and Export Promotion Competitiveness

Eddleston [13] defined the niche strategy as the use of specified needs from the customers as the main consideration to provide product satisfaction. Other researchers also define niche differentiation strategy as the way to customize products for the specific needs of both domestic and international markets where there are few competitors. In addition, it emphasizes product personalization and specialization [31–40]. This can be applied to create differentiation as well as to help understand the competitive situation faced by today's organizations [10]. Niche differentiation has a significant impact on export promotion competitiveness, encouraging the exporters to have unique and specialized goods. When firms have unique and desirable craft products responding to the customer's needs, they will receive more competitive export promotion programs such as the opportunity to access government subsidies, financial support, market information support, and others, compared to the other competitors. Supportively, the study from Maina and Kagiri [41] demonstrates that product differentiation strategies can influence business competitiveness; meanwhile, Safrianti et al. [42] illustrate that differentiation strategy for product innovation can influence competitiveness in the global market. In addition, accordingly, the hypothesis can be developed as follows:

Hypothesis 1 (H1): *Niche differentiation strategy has a positive impact on export promotion effectiveness.*

2.1.2. Export Promotion Competitiveness and Export Performance

Export promotion competitiveness refers to the way to foster the potential to export products to other countries [19]. It can encompass government and related agencies' information provision, accessible investment budget and interest for small enterprises, marketing consultancy, and law and policies [18–22]. Geldres-Weiss and Monreal-Perez [18] studied the influence that export promotion programs have had on trade fairs, and trade missions connected to export activities for Chilean companies and revealed the effect of export promotion programs on Chilean firms' export activity at trade shows and trade missions. Competitive export promotion can influence export performance, including market reputation, profitability, customer satisfaction, and internal business improvement. Malca et al. [22] studied export promotion programs as export performance catalysts for SMEs (small and medium enterprises) in the emerging economy. They found that the government supported the promotion program, including trade mobility-, information-, education-, and training-related programs, which can provide the resources for SMEs oriented towards export activity and current export performance. In reference to Malca et al. [22], it is necessary for a subsequent study to evaluate the efficiency and design of export promotion programs, taking into account the resources at the disposal of SMEs and the internationalization theories of the firm. This will increase the impact that export promotion programs have on SMEs' international development and export performance. Accordingly, the hypothesis can be developed as follows:

Hypothesis 2 (H2): *Export promotion competitiveness positively impacts export performance.*

2.1.3. Niche Differentiation Strategy and Export Performance

Based on a literature review related to niche differentiation strategy, Eddleston et al. [13] defined that the niche differentiation strategy focuses on the customers' needs to create their satisfaction. Solberg and Durrieu [38], Vorhies et al. [40], and Yarbrough et al. [40] explain that niche differentiation strategy is the way to customize products for the specific needs of the foreign market, to focus on a specific target market with few competitors and a particular type of customer or geographic area. Cannatelli et al. [14] stated that firms pursuing niche strategies could link product quality and performance. Indeed, Geldres-Weiss and Monreal-Perez [18] studied the export performance of Chilean companies and revealed that export performance could be measured by market reputation, profitability, customer satisfaction, and internal business improvement. Freixanet and Churakova [19] measured export performance using various intermediate and ultimate export marketing outcomes and performance metrics, such as awareness, usage, and the sense of usefulness. Accordingly, the hypothesis can be developed as follows:

Hypothesis 3 (H3): *Niche differentiation strategy has a positive impact on export performance.*

2.1.4. Niche Differentiation Strategy, Export Promotion Competitiveness and Export Performance

According to the literature review on export promotion competitiveness and export performance, it should be mentioned that niche differentiation strategy plays an important role in creating export promotion competitiveness and export performance. Porter [10] pointed out that a niche differentiation strategy links to creating organizational competitiveness and helping to understand the competitive situation organizations face. Freixanet and Churakova [19] applied export promotion using information acquisition, export consultancy, and export investment support to create export promotion competitiveness and competency, which links to export performance. Furthermore, Cannatelli et al. [14,15] suggest that firms implementing niche strategies can improve product quality and firm performance. Accordingly, the hypothesis can be developed as follows:

Hypothesis 4 (H4): *Export promotion competitiveness mediates the relationship between niche differentiation strategy and export performance. All purposed hypotheses are shown in Figure 1.*

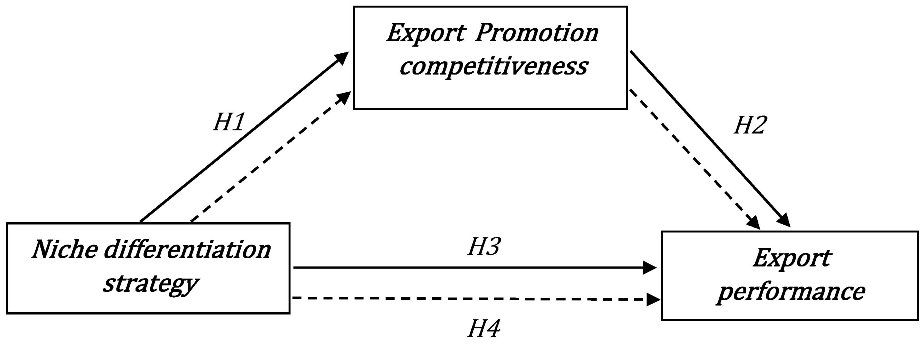

Figure 1. Hypothesis framework.

2.2. Research Methods

In response to the study objectives, the study adopts a quantitative approach. The population in this study were craft product companies using marine transport, but the numbers of the population are unknown. Therefore, the study samples were drawn using Cochran's method [43]. Consequently, 400 employees from 46 craft product companies exporting using marine transport were selected at a confidence level of 95%. The research tool was a questionnaire survey. Prior to data collection, a systematic item-objective congruence (IOC) with five experts from marketing and international business was used to indicate content validity; Cronbach's alpha drawn from 50 sets of the pre-test was also employed to test the item reliability. The analysis indicated that the IOC was equal to 0.942, and Cronbach's alpha for niche differentiation strategy, export promotion competitiveness and export performance was 0.964, signifying that the research instrument, based on Hair et al. [44], was appropriate.

In terms of the measures used in this study, there were three main constructs: niche differentiation strategy, export promotion competitiveness, and export performance covering financial and market performance. For niche differentiation strategy, the items adopted from Ibrahim [36], Dalgic and Leeuw [37], Solberg and Durrieu [38], Vorhies et al. [39], and Yarbrough et al. [40] involved product customization, differentiation, specialization, high quality, and market specification. The measure of export promotion competitiveness adopted from Freixanet [45] consisted of direct promotion, consultancy, investment support, information acquisition, and entrepreneurs with an international orientation. The measure of export performance comprising financial and market performance was derived from Solberg and Durrieu [38], focusing on profitability, sales volume, operation growth, market share increase, export opportunity, export awareness, and strategic market position. The items used in the questionnaires can be seen in the Table 1.

The questionnaire with 7 scales was used to collect data from 400 employees working in 46 exporting craft product companies by employing the purposive sampling method. Cronbach's alpha with 0.967 indicates the data reliability. Confirmatory factor analysis (CFA) was used to assess the model fitness and convergent and discriminant validity, as shown by factor loading (FL), composite reliability (CR), average variance extracted (AVE), correlation matrix, and the square root of AVE. It was predicted that the examined model gives satisfactory goodness-of-fit indices. However, when the model was determined to be unfit, it was permitted to be altered using modification indices [49]. For hypothesis testing, structural equation modeling (SEM) with bootstrapping technique was employed. After the results of the study were drawn together, the findings were explained and discussed.

Table 1. The items used in the questionnaires.

Items	Adopted From
STRN1: Our company customizes products for the specific needs of foreign markets. STRN2: Our company focuses on a specific target market where there are few competitors. STRN3: Our company focuses on a particular type of customer or geographic area STRN4: Our company develops specific craft markets. STRN5: Our company's products are so specialized. STRN6: Our company differentiates our products from our competitors. STRN7: Our company maintains a high-quality standard for our crafts. STRN8: Our company maintains the high quality of our craft skills.	[36,38–40]
EXCP1: Our firm gets direct promotion. EXCP2: Information acquisition (includes information on markets, programs or export know-how, and use of foreign trade offices. EXCP3: Our firm gets consultancy from an outsourcing company. EXCP4: Our firm gets investment support from the financial institution. EXCP5: Our firm aims to obtain sales leads in the market. EXCP6: Improvements in Marketing Managers' international orientation.	[19,45]
PER1: Our international operations have been very profitable. PER2: Our international operations have generated a high volume of sales. PER3: Our international operations have achieved rapid growth. PER4: Actions were taken to increase profitability. PER5: Our international operations have improved our international competitiveness. PER6: Our international operations have strengthened our strategic position. PER7: Our international operations have significantly increased our international market share. PER8: The goal is to attain a firm foothold in a new market. PER9: The goal is to gain knowledge opportunities. PER10: The goal is to acquire knowledge of export practices. PER11i: Increased awareness of products in export markets.	[38,46–48]

3. Results and Discussion

3.1. Respondents' Profiles

Most employees responding to the questionnaires were female (188 persons or 47.0%), male (184 persons or 46.0%), and others (28 persons or 7.0%). In terms of age, there were 165 persons (41.3%) aged 31–40 years old, 121 persons (30.3%) aged 21–30 years old, 69 persons (17.3%) aged 41–50 years old, 18 persons (4.5%) aged below 20 years old and three persons (0.8%) aged above 60 years old. In terms of education level, nearly 50% of respondents graduated with below a bachelor's degree (188 persons), 154 persons with a bachelor's degree (38.5%), and 58 persons with an above bachelor's degree (14.5%). Regarding their position, 239 persons (59.8%) worked in operational positions, while 161 persons (40.3%) worked in managerial positions such as business owners, executives, and department and divisional managers. Lastly, 187 persons (46.8%) had completed less than ten years working experience in exporting companies, 155 persons (38.8%) with 10–20 years, and 58 persons (14.5%) with more than 20 years.

3.2. Niche Differentiation Strategy, Export Promotion Competitiveness, and Export Performance

From Table 2, the study revealed that niche differentiation strategy, export promotion competitiveness, and export performance had mean scores ranging from 4.428 to 5.428 and standard deviations ranging from 0.837 to 1.280. In addition, the study found that the studied variables gained acceptable skewness values ranging from −0.545 to 0.224 and kurtosis values from −1.061 to −0.021 which were under ± 3.00 meaning that all variables were appropriate for further analysis.

Table 2. Descriptive statistics for niche differentiation strategy, export promotion competitiveness, and export performance.

Variables	Max	Min	Mean	Std. Deviation	Skewness	Kurtosis
STRN1	3	7	4.518	0.801	−0.175	−0.443
STRN2	3	7	4.700	0.929	−0.181	−0.757
STRN3	2	7	4.458	0.860	0.061	−0.410
STRN4	2	7	4.963	0.937	−0.494	−0.411
STRN5	3	7	5.160	1.038	−0.500	−0.655
STRN6	3	7	4.958	1.004	−0.213	−0.560
STRN7	3	7	5.428	1.142	−0.454	−0.630
STRN8	2	7	4.965	1.180	0.224	−0.775
EXCP1	3	7	4.778	0.906	−0.299	−0.517
EXCP2	3	7	4.963	1.073	−0.236	−0.923
EXCP3	3	7	5.150	1.213	−0.121	−0.916
EXCP4	3	7	5.208	1.280	−0.220	−1.061
EXCP5	2	7	4.575	0.947	−0.057	−0.527
EXCP6	3	7	4.740	0.992	−0.063	−0.679
PERF1	3	7	4.920	0.837	−0.545	−0.021
PERF2	3	7	4.578	0.925	0.000	−0.695
PERF3	3	7	4.980	1.013	−0.439	−0.827
PERF4	3	7	4.948	0.965	−0.365	−0.482
PERM1	2	7	4.625	0.842	−0.366	−0.316
PERM2	2	7	4.910	0.985	−0.468	−0.663
PERM3	2	7	4.783	0.953	−0.217	−0.439
PERM4	2	7	4.958	1.072	−0.419	−0.710
PERM5	2	7	4.880	0.952	−0.384	−0.451
PERM6	2	7	4.700	0.932	−0.168	−0.609
PERM7	2	7	4.930	0.896	−0.497	−0.296

3.3. Model Development, Convergent Validity, and Discriminant Validity

Confirmatory factor analysis was conducted to investigate convergent and discriminant validity of niche differentiation strategy, and the export promotion competitiveness and export performance of craft products. Goodness-of-fit indices show $\chi^2/\text{df} \leq 3.00$, GFI $\geq$ 0.90, CFI $\geq$ 0.90, NFI $\geq$ 0.90, AGFI $\geq$ 0.90, RMSEA $\leq$ 0.07, and RMR $\leq$ 0.08 were considered both before and after model adjustment. The initial model revealed unacceptable values with Cmin/df = 6.198, p-value = 0.000, GFI = 0.693, AGFI = 0.634, RMR = 0.067, RMRSEA = 0.114, TLI = 0.842, CFI = 0.856, and NFI = 0.834. However, the values of goodness-of-fit indices were improved when the adjusted model was tested, with Cmin/df = 1.186, p-value = 0.054, GFI = 0.963, AGFI = 0.925, RMR = 0.030, RMRSEA = 0.022, TLI = 0.994, CFI = 0.997, and NFI = 0.981. The adjustment was made by correlating the variables indicated by modification indices with the threshold of 0.4 [44]. In addition, the factor loadings, composite reliability, and average variance extracted from studied variables were considered, which should be greater than 0.05 in order to explain unidimensional measures [49], as shown in Table 3. All the variables' factor loadings are shown in Table 4.

Table 3 shows that all factor loadings were about 0.564–0.942 for niche differentiation strategy, 0.778–0.911 for craft products' export promotion competitiveness, and 0.675–0.978 for export performance. The result also revealed composite reliability ranging from 0.908–0.939 and average variance extracted ranging from 0.633–0.939. These values were higher than 0.50, meaning that all variables could be further analyzed [49]. In addition, the correlation matrix and square root of AVE were considered for convergent and discriminant validity. Table 4 shows related values.

In Table 4, the variables are correlated at the acceptable level, all variables have correlation coefficients lesser than 0.8 as recommended by Henseler et al. [50], and the square root of AVE was higher than the correlation coefficient matrix of the variables. This means that all variables, including niche differentiation strategy, craft products' export promotion competitiveness, and export performance were identical and appropriate to be further analyzed.

Table 3. Factor loadings and convergent validity.

Variables	STRN	EXCP	PER	CR	AVE
STRN1	0.669				
STRN2	0.750				
STRN3	0.564				
STRN4	0.861			0.928	0.623
STRN5	0.942				
STRN6	0.822				
STRN7	0.912				
STRN8	0.719				
EXCP1		0.911			
EXCP2		0.866			
EXCP3		0.893		0.940	0.719
EXCP4		0.902			
EXCP5		0.805			
EXCP6		0.778			
PER1			0.830		
PER2			0.749		
PER3			0.978		
PER4			0.827		
PER5			0.701		
PER6			0.906	0.952	0.624
PER7			0.910		
PER8			0.940		
PER9			0.791		
PER10			0.675		
PER11			0.767		

Note: STRN 1–8 = niche differentiation strategy, EXCP1–6 = export promotion competitiveness, and PER1–11 = export performance.

Table 4. Discriminant validity.

Variables	STRN	EXCP	PER
STRN	0.789		
EXCP	0.761	0.848	
PERF	0.761	0.704	0.801

Note: STRN = niche differentiation strategy, EXCP = export promotion competitiveness, and PER = export performance.

3.4. Finalized Model and Hypothesis Analysis

After assessing convergent and discrimination validity using confirmatory factor analysis (CFA), the finalized model was constructed, and structural equation modelling (SEM) was performed to investigate the hypothesis. Consequently, the final model was initially investigated, and its goodness-of-fit indices were unacceptable since they did not meet the recommended criteria: Cmin/df = 6.198, p-value = 0.000, GFI = 0.693, AGFI = 0.634, RMR = 0.067, RMRSEA = 0.114, TLI = 0.842, CFI = 0.856, and NFI = 0.834. However, the model was adjusted based on modification indices recommendation and its goodness-of-fit indices were then improved, Cmin/df = 1.182, p-value = 0.056, GFI = 0.962, AGFI = 0.924, RMR = 0.031, RMRSEA = 0.021, TLI = 0.994, CFI = 0.997, and NFI = 0.981 (Figure 2).

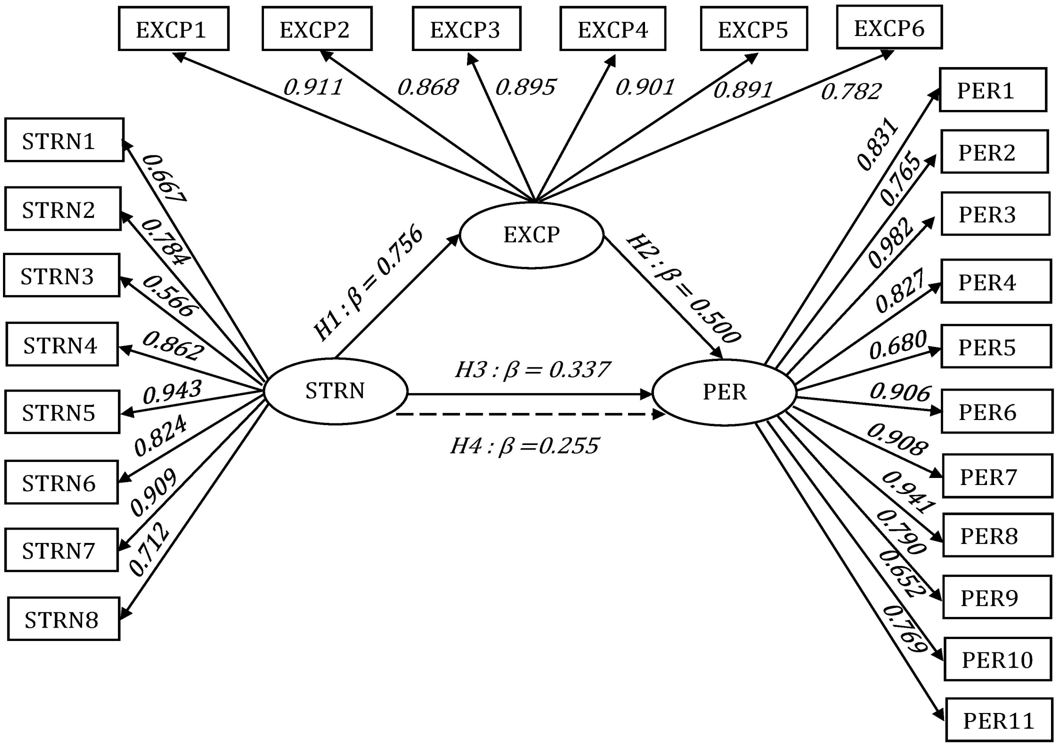

Figure 2. Finalized model.

Table 5 shows the results of the hypothesis investigation and the predictive ability of impact prediction on variables. Hypothesis 1 (H1) presents that niche differentiation strategy has a positive impact on export promotion competitiveness (β = 0.756, $p < 0.05$), while hypothesis 2 (H2) implies that export promotion competitiveness has a positive impact on export performance (β = 0.337, $p < 0.05$). Hypothesis 3 (H3) reveals that niche differentiation strategy has a positive impact on export performance, including financial performance and market performance (β = 0.500, $p < 0.05$) at the statistically significant level of 0.001.

Table 6 presents that the niche differentiation strategy in hypothesis 4 (H4) has a significant indirect impact with a partial mediating role on export performance through the export promotion competitiveness of craft products since the *p*-value from the bootstrapping technique was lower than 0.05.

Table 5. Standardized estimate, unstandardized estimate, standard error, *t*-value, z-value, and *p*-value.

Variables	Unstandardized Estimate (b)	Standardized Estimate (β)	S.E.	*t*-Value	*p*-Value
H1: STRN → EXCP	0.750	0.756	0.055	13.607	***
H2: EXCP → EXPER	0.283	0.337	0.040	7.112	***
H3: STRN → EXPER	0.417	0.500	0.046	8.974	***

Note: STRN = niche differentiation strategy, EXCP = craft products export promotion competitiveness, and PER = export performance. *** *p*-value = < 0.001.

Table 6. Mediating effect result.

Variables	IV-N-DV		Mediating Type
	Direct	Indirect	
H4: STRN → EXCP → EXPER	0.500 *	0.255 **	Partial Mediation

Note: STRN = niche differentiation strategy, EXCP = craft products export promotion competitiveness, and PER = export performance. ** p-value = < 0.01, * p-value = < 0.05.

4. Discussion

Based on the study results, the discussion considers the hypothesis investigation. This study showed that niche differentiation strategy positively impacts the export promotion competitiveness of craft products and export performance, including financial and market performance at a statistically significant level. This indicates that it can create uniqueness and specify products for the target market. Cannatelli et al. [14] argued that corporations following niche strategies using brand management techniques, such as effective communication with internal and external clients, might relate to product quality and company success. In addition, Wang [11] shows that product differentiation might be related to businesses' economic, environmental, and social sustainability. To develop a suitable niche differentiation approach, Maulina and Raharja [15] suggest including a SWOT analysis. In addition, Chang et al. [16,17] reinforced that Taiwan's traditional handicrafts be enhanced to increase corporate competitiveness.

Export promotion competitiveness can have a positive impact on business performance from both market and financial aspects. This is because assistance from related organizations and sectors, especially the government, can help the entrepreneurs increase business success. This finding was supported by the study by Geldres-Weiss and Monreal-Perez [18], who examined the impact of export promotion programs on the export activity of Chilean enterprises during trade exhibitions and missions and found that export promotion programs can increase export activity. In addition, Freixanet and Churakova [19] conducted a study in Russia on the impact of export promotion programs on firms' export competencies and performance in a transition economy and discovered that awareness, use, perceived usefulness, and various intermediate export marketing strategies all play a significant role.

The craft products' export promotion competitiveness had a mediating effect on the relationship between niche differentiation strategy and export performance. This is due to the fact that export promotion can help increase financial performance as well as market performance, which include profitability, sales volume, operation growth, market share increase, export opportunity, export awareness, and strategic market position. This is accomplished through an increase in export promotion competitiveness, in which the company can have direct promotion, excellent knowledge of markets, programs, export know-how, good consultation, strong investment support, and clear export vision. These are all important components for successful exportation [18,19].

This study contributes to three main perspectives: practical, theoretical, and policy. In practice, the managers of the exporting companies should emphasize good planning for the implementation of niche differentiation strategy, especially in making products more specialized, maintaining high quality, and developing specific craft markets. So, companies can achieve export promotion competitiveness and export performance from both financial and market perspectives. For the theoretical contribution, the study's findings can confirm the effect of niche differentiation strategy and the export promotion competitiveness on export performance from financial and market performance. The authors of the study also found it interesting that export promotion competitiveness can have a role in mediating the impact of niche differentiation strategy on its effectiveness. This can guide future research to find which factors play a mediating role in bettering craft businesses' export performance. In policy, the government and related agencies should establish and provide policy in delivering information related to market, know-how, foreign trade offices and investment support.

5. Conclusions

This study analyzed the niche differentiation strategies and competitiveness of exporting craft products using structural equation modelling (SEM). Analysis was conducted using the data from employees working in 46 craft-product-exporting companies in Thailand. The results showed that four hypotheses were supported at a statistically significant level. Niche differentiation strategy had a positive impact on export promotion competitiveness. Export promotion competitiveness and niche differentiation strategy had a positive impact on export performance.

A bootstrapping technique was used to investigate the mediating effect of export promotion competitiveness on the factorial relationship between niche differentiation strategy and export performance. The result indicated that niche differentiation strategy positively impacts export performance partially mediated by export promotion competitiveness. Accordingly, this study can be found advantageous for a practical, theoretical and political contribution. From practical perspectives, the managers can strategize making more specialized products, maintaining high quality, and developing specific craft markets. From theoretical perspectives, the study can affirm the relationships between niche differentiation strategy, export promotion competitiveness, and export performance. From a political perspective, the study can guide the government and related agencies to establish and provide governmental services and policies to enable better craft product export performance.

This paper is subject to some limitations that can be considered in future research. This study emphasized only niche differentiation strategy, export promotion competitiveness, and export performance. Other factors, such as digitalization or global transportation and risk management during a crisis, should be considered in future research. Moreover, the study only applied a quantitative research approach. Future research should adopt quantitative or mixed-method approaches accompanying in-depth interviews or focus groups to gain insight into business strategy. Lastly, the study pinpoints only a general transportation mode, when it may be necessary to consider specific modes of transportation so that the research results can be utilized more effectively. Marine transportation is considered to be one of the important modalities. It plays an important role in more than three-quarters of all product exports and helps to promote economic growth and the development of jobs in various nations. Future research could focus on marine transportation with specific contributions from managerial, theoretical, and political perspectives. For a practical and theoretical contribution, the managers and academicians could perhaps focus on the related factors and practices influencing export performance through the marine transport mode. The government could use the study results related to marine transport to devise export promotion programs and policies to enhance the opportunities of export business entrepreneurs to optimize export promotion competitiveness and performance.

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The Impact of Export Promotion Programs on Export Competitiveness and Export Performance of Craft Products

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Abstract: International trade is defined as economic transactions between countries worldwide. Promoting the export of craft products, which are valued products, is critical for international business as the sales growth increases worldwide. Moreover, the export of craft products has increased international trade and maximized economic value in the highly competitive global market. Therefore, businesses need to be promoted to increase their competitiveness. This study explores the impact of export promotion programs on export competitiveness and the performance of craft products. A self-administered questionnaire was used to correct the data. There were 400 respondents completing the questionnaires, who were working in craft product export companies using marine transport. The data analysis is conducted by using Structure Equation Modelling (SEM). The findings show that the export promotion program has a significant positive relationship with export competitiveness. A positive relationship between export competitiveness and export performance is also found. The results indicate that export competitiveness fully mediates the relationship between export promotion programs and export performance. The findings from this study contribute to craft product export businesses and provide a practical exporting approach. Marine transport is one of the critical international entry modes many companies use to expand businesses. It should be noted that shipping cost savings are related to export efficiency.

Keywords: export promotion programs; export competitiveness; export performance; marine transportation; craft products

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1. Introduction

Recently, it has been impossible to avoid the topic of globalization and the global market, in which enterprises compete against foreign rivals in their home markets, even if they have not yet internationalized themselves [1]. Consequently, in a more dynamic and competitive global marketplace, businesses are pushed to expand beyond their national boundaries and boost their competitiveness in both local and international markets and within their own industries. At this stage, exporting becomes a tool for businesses to use in order to extend their reach into new international markets, increase their sales, and more effectively compete against global competitive pressures [2].

Export business has significant impacts on investment expansion and creating labor demand at both national and international levels [2,3]. Many enterprises need to establish their branches in other countries to ensure that they have a place that can store their products when they are exported or they need to tie alliances with national and international partners to facilitate the conveniences of exportation activities [4]. This expansion requires substantial financial capabilities and a large investment in resources. In addition, the export business can assist in the import of foreign currency as well as contribute to the efficient use of resources because entrepreneurs have to consider effectively utilizing and flowing business resources such as labor, technologies, methods, materials, and finances, on a national and international level in order to obtain business competitiveness [5]. Lastly, the export business can create added value to resources because the entrepreneurs are required to create and provide product and service exportation to satisfy the different customers' preferences. Herewith, the entrepreneurs must attempt to understand the customers' needs and demands from different perspectives, including cultures, technologies, politics, and economic relevancies [6].

However, export entrepreneurs are encountering difficulties in achieving export performance. For example, the exporters lack professional, proactive marketing skills as well as export-related knowledge such as technology provision, export business know-how, and international experiences to compete with foreign competitors. In addition, the problem of high labor costs, which affects production costs, causes the prices of products and services to rise, which in turn increases the inability to compete with other competitors that can gain competitive advantages [7,8]. Furthermore, Jung et al. [9] reveal that the important analysis of decision-making factors for selecting an international freight transportation mode can influence business performance. At the same time, Fulzele et al. [10] suggest that it is necessary to consider the selection of transportation modes that can be linked to business success and sustainability.

Marine transport is one of the major forms of exportation. Given its importance, marine transport has been extensively studied in previous research. Many publications on maritime transport-related topics have been published in the last few decades [11]. Marine transport comprises a large variety of operations and, in combination with port activities and logistic hubs, has a substantial impact on the development of marine industry and trade, hence promoting economic growth and employment creation [12]. In Thailand, marine transportation is crucial for the country since there are various areas with access to rivers, seas, and oceans that are trading products with other counties such as China, Hong Kong, and so on [13,14]. Krailasuwan [13] indicated that maritime transportation accounted for about 90% of Thai imports and exports. In order to determine how to advance maritime trade liberalization, the CHINA–ASEAN free trade area regionally liberalizes marine service trade to facilitate international transportation in global trade [15]. However, Wei [14] and Lu [15] report that having international trade to export and import products to and from foreign countries, such as Thailand, requires considering ways to improve competitive business advantages such as satisfactory prices, product uniqueness as well as government support.

Freixenet and Churakova [16] found that export promotion programs can assist entrepreneurs in reaching their goals in creating firms' export competencies. Additionally, Coudounaris [17] demonstrates that the export promotion program can affect export performance. Therefore, it is necessary to study how to improve the export performance for the export business by studying export promotion programs that can bring about better business competitiveness and performance. This study aims to study the impact of export promotion programs on export competitiveness and export performance in the craft product export firms in Thailand since these firms have promoted craft products made by people from the community. If these firms can gain export competitiveness and export performance, they can finally create sustainable community development and links to increase the national economy. In addition, this article aims to suggest the implication of using marine transport. To display the study content, this article begins with an introduction that describes the significance of this study and the objectives. The next section portrays the study materials and methodology. Then, the research findings as well as a discussion of the results, research contribution, and future research recommendations, are composed.

2. Materials and Methods

2.1. Export Promotion Program and Export Competitiveness

Export competitiveness is significant for the export business because it can positively influence export performance, including financial and market performance [18,19], a nation's sustainable development and foreign trade [20], and advantages in emerging markets [21]. Various studies [17,22–25] mention that the export promotion program provided by the government increases export competitiveness. This refers to the role of the government in offering the support related to the export, providing activities encompassing financial and tax incentives, trade fairs participation, market research (specific information), export training, and export consultation [26]. Similarly, Coudounaris [17] defines the export promotion program as the function of the governments or associated governmental entities that aim to encourage the exporting activity of a nation via its local businesses. Indeed, export promotion activity can support multi-modal freight transportation since it can improve the sustainability of the business by minimizing the transportation expenses, product damages, released pollutants, and road congestion, as well as by boosting the delivery speed. In addition to adopting export promotion activities for marine transport, Akims and Danyil [27] reveal that infrastructures such as electronic export clearance and the stability of the country's power supply via the ongoing expansion of energy distribution lines could lead to benefit export performance and finally link to export-led economic growth.

Consequently, the terms of the export promotion program found various advantages to all levels, including international, national, sectoral, and company levels from public, public or multi-sectoral non-profit, non-profit, and private sectors [28]. The export promotion program can influence firms' competitiveness, including product differentiation, product quality, and promotion effectiveness [22–25]. In addition, Freixanet and Churakova [16] show that export promotion programs are important for Russian manufacturers since they can assist the entrepreneurs in reaching their goals in creating firms' export marketing competencies by highlighting clear issues regarding program awareness, availability, and accessibility related to exportation. According to Njinyah [29], government policies for export promotion may provide possibilities for businesses to acquire competitiveness in terms of nation and market characteristics, understanding of trade obstacles in the export market, and the correct product marketing mix. Similarly, Catanzaro and Teyssier [30] revealed that export promotion programs might be associated with the growth of export capabilities and the adoption of risk management techniques. According to Mata et al. [31], financial and marketing support from government policy may help young entrepreneurial firms to overcome the susceptibility of being new and small while gaining competitive export capabilities. Adedoyin et al. [32] added that the government should ensure macroeconomic and political stability to achieve export. Accordingly, we propose the hypothesis that H1: export promotion program can influence export competitiveness.

2.2. Export Competitiveness and Export Performance

Export competitiveness refers to the ability to take action on exportation compared to other competitors, such as product differentiation, product quality, and promotion effectiveness [22–25]. In terms of product differentiation, Guru and Paulssen [25] and Priede [33] explain that entrepreneurs can have the ability to produce unique products for the export market, have a differentiated image compared to competitors in the international market, and create a design that is in accordance with the wishes of consumers. Meanwhile, Boehe, and Barin Cruz [22] and Guru and Paulssen [22] demonstrate that entrepreneurs can have export competitiveness in terms of product quality by having products that meet a standard and that are superior compared to the quality of their competitors in the international market. Similarly, Freixanet [23] illustrates that exportation entrepreneurs can gain export competitiveness by obtaining the direct export promotion, receiving information on markets, programs, or export know-how, and use of foreign trade offices, having consultancy, seeking investment support, obtaining sales leads as well as improving marketing managers' international orientation. Export competitiveness has a positive effect on export performance. As regards export performance, it can be categorized into two main dimensions, including financial and market performance [18,19]. The financial performance involves profitable foreign operations, strong sales, quick expansion, and enhanced profitability. Market performance refers to the international operations that enhance international competitiveness, strengthen the firms' strategic position, significantly increase the international market share, establish a foothold in new markets, identify export opportunities, and increase product awareness in export markets. Various studies indicate the effect of export competitiveness on export performance. For instance, Boehe and Barin Cruz [22] found that export competitiveness in terms of product differentiation can be linked to export performance. In the meantime, Priede and Pereira [24] show that EU promotion program competitiveness can establish export performance. Lastly, Keskin et al. [34] explain that competitiveness, including differentiation, can increase export companies to obtain export performance in foreign markets. Accordingly, the hypothesis can be that H2: export competitiveness can influence export performance.

2.3. Export Promotion Program and Export Performance

Various studies indicate the effect of export promotion programs on export performance since the support from the government and related export agencies such as financial and tax incentives, trade fairs participation, market research (specific information), export training, and export consultation can enhance the entrepreneurs gain export performance from both financial and market perspectives such as profitability, high volume of sales, export opportunities, international experiences, a firm's strategic position as well as a foothold in the new market [18,19,28]. Moreover, Coudounaris [17], studying export promotion programs assisting SMEs, demonstrates that the export promotion program can influence the export performance, including knowledge, capabilities, competitive advantage, and business experience. Accordingly, the hypothesis can be that H3: export promotion program can influence export performance.

2.4. Export Promotion Program, Export Competitiveness and Export Performance

There are studies regarding the significant impact of export promotion programs on export competitiveness and export performance. For example, Njinyah [29] found that government policies for export promotion can be linked to creating competitiveness in terms of exportation. Additionally, Catanzaro and Teyssier [30] reveal that export promotion programs can assist the entrepreneurs in obtaining the growth of export capabilities. In addition, Coudounaris [17] demonstrates that the export promotion program could link the export performance, including knowledge, capabilities, competitive advantage, and experience. Meanwhile, a study by Keskin et al. [34] also revealed that unique company capabilities could provide the opportunity for the export businesses in international markets and increase the performance of foreign markets' exports. However, there are some studies demonstrating that export promotion programs may not directly influence export performance. For example, Njinyah [29] found that the government's export policy did not directly affect export performance. Moreover, Mata et al. [31] indicate that the support from related institutions requires competitive capabilities to play a mediating role, which can finally affect the enterprises' export performance. Accordingly, the hypothesis can be that H4: export competitiveness mediates the relationship between export promotion program and export performance. All hypotheses are illustrated in Figure 1.

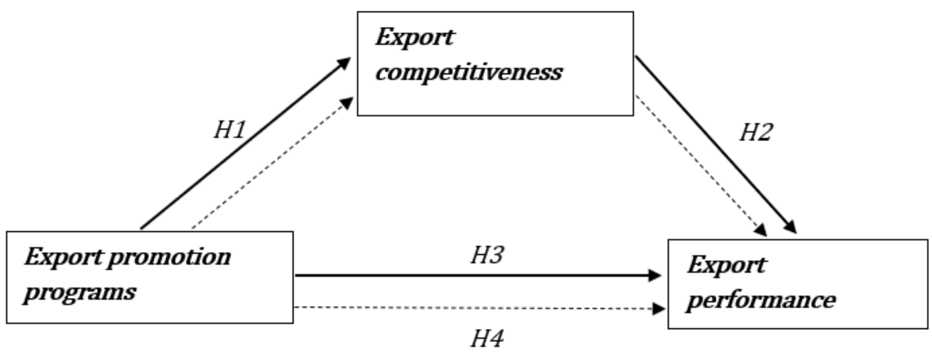

Figure 1. Conceptual Framework.

2.5. Research Methods

In response to the study objectives, the study was then designed to adopt a quantitative research approach. The population in this study was craft product companies in Thailand. The sample size was calculated according to the general rules of choosing the Alpha level of confidence, and the acceptable error value is Alpha = 0.05 and acceptable error values of 5%, which are considered suitable values Krejcie and Mogan [35] because in this study the population numbers were unknown; therefore, the proportion of the population that needs to be chosen is set at 20% or 0.2 at the confidence level of 95%, and the error value of 5% or 0.05, by using the formula to calculate the suitable number of samples by using the methodology of Cochran's method [36]. This method is appropriate for calculating the sample size of a large population whose degree of variability is unknown [37,38]. As many craft companies are exporting their products abroad, the number of companies and their employees is unknown. Furthermore, there is a lack of information regarding the product types and the size of businesses. Thus, Cochran's approach [36] was used to determine the sample size of this study. The formula and calculation are presented below.

The Cochran formula is:

$$n_0 = \frac{Z^2 pq}{e^2}$$

where:
e is the desired level of precision (i.e., the margin of error),
p is the (estimated) proportion of the population that has the attribute in question,
q is $1 - p$.

Replaced by the following.

The study set p equal to 0.5, and 95% confidence was the target, allowing at least ± 5 percent error. Herewith, a 95% confidence level provides Z values of 1.96. Accordingly, the corresponding numbers are assigned as follows.

((1.96)2x (0.5) (0.5))/(0.05)2 = 385.

Consequently, there were 400 (rounded) employees from craft product companies using marine transport that were selected at a confidence level of 95%, which covered the appropriate sample according to Cochran's formula [36], while also obtaining larger samples. This was an advantage in terms of reliability and representation based on the population of Newman [39]. The research tool was a questionnaire survey. Prior to data collection, a systematic item-objective congruence (IOC) with five experts from marketing, international business, and statistic fields was used to indicate content validity. Cronbach's alpha drawn from 50 sets of pretests was employed to analyze the item reliability. Regarding the pretest study, the result indicated that most of the respondents were female (50.0%), aged between 31–40 years old (46.0%), graduated with lower than a bachelor's degree (58.0%), worked as operational staff, and had less than 5 years of export experience. In addition, the analysis indicated that the IOC is equal to 0.942 and Cronbach's alpha is 0.980, indicating that the research instrument has the appropriate quality [40].

In terms of the measures in this study, there are three major perspectives: export promotion programs, export competitiveness, and export performance. Export promotion program items were adopted from Cuyvers et al. [28] using a 7-rating scale, where 1 signifies extremely unimportant and 7 signifies extremely important. For export competitiveness, there are three dimensions: product quality, product differentiation, and promotion effectiveness. Firstly, for product quality, the items were adopted from Boehe and Barin Cruz [22], Guru and Paulssen [25], and Magnani and Zucchella [41] meanwhile, the items associated with product differentiation were adopted from Boehe and Barin Cruz [22], Guru, and Paulssen [25], and Priede [33]. Lastly, the items pertaining to promotion effectiveness were adopted from Freixanet [23] using a 7-rating scale indicating 1 to refer to extremely unimportant and 7 to refer to extremely important. For export performance, there are two concepts: financial performance and market performance adopted from

Francis and Collins-Dodd [18] and Solberg and Durrieu [19], asking about profitability, sales volume, operation growth, market share increase, export opportunity, export awareness, and strategic market position using 1 to refer extremely unsatisfactory and 7 to refer extremely satisfactory.

To obtain the data, the questionnaire was distributed to 400 employees from 46 exporting craft product companies using marine transport by employing the purposive sampling method. The data were collected from February to April 2022. Cronbach's alpha was used to indicate the data reliability. From the study, Cronbach's alpha was 0.921 for the export promotion program, 0.969 for export competitiveness, and 0.936 for export performance.

Then, confirmatory factor analysis (CFA) was used to assess the model fitness as well as convergent and discriminant validity, as shown by factor loading (FL > 0.5), composite reliability (CR > 0.5), average variance extracted (AVE > 0.5), correlation matrix, and the square root of AVE. It was predicted that the examined model would give satisfactory goodness-of-fit indices which include Chi-square Probability Level (p-value > 0.05), Relative Chi-square (CMIN/df < 3), Goodness of Fit Index (GFI > 0.90), Root Mean Square Error of Approximation (RMSEA < 0.08), Root mean square residual (RMR < 0.05), Tucker and Lewis (TLI > 0.90), Normed Fit Index (NFI > 0.90), and Adjusted Goodness of Fit (AGFI > 0.90). However, when the model was determined to be unfit, it was permitted to be altered using modification indices. For hypothesis testing, structural equation modeling (SEM) with bootstrapping technique was employed [40]. After the result of the study was drawn, the findings were explained and discussed.

3. Results

3.1. Respondents' Profiles

From 400 employees, the majority of the workers who responded to the surveys were female (47.0%), male (46.0%), and others (7.0%). Regarding the respondents' age, there were 41.3 percent aged between 31 and 40 years old, 30.3 percent aged between 21 and 30 40 years old, 17.3 percent aged between 41 and 50 40 years old, 4.5 percent aged below 20 40 years old, and 0.8 percent aged older than 60 40 years old. In terms of education level, the majority of respondents graduated with less than a bachelor's degree (47.0%), followed by a bachelor's degree (38.5%), and above a bachelor's degree (14.5%). In terms of their position, 59.8 percent are in operational roles, while 40.3% are in management roles such as firm owners, executives, department managers, and division managers. Lastly, 46.8 percent had less than 10 years of experience working in exporting organizations. Meanwhile, 38.8 percent had 10–20 years of experience, and 14.5 percent have more than 20 years of experience.

3.2. Model Development, Convergent Validity, and Discriminant Validity

Confirmatory factor analysis was conducted to investigate convergent validity and discriminant validity of export promotion programs, export competitiveness, and export performance. Good-fitness indices: $\chi^2/\mathrm{df} \leq 3.00$, GFI ≥ 0.90, CFI ≥ 0.90, NFI ≥ 0.90, AGFI ≥ 0.90, RMSEA ≤ 0.07, and RMR ≤ 0.08 were considered both before and after model adjustment. The initial model revealed unacceptable values: Cmin/df of 6138, p-value of 0.000, GFI of 0.830, AGFI of 0.765, RMR of 0.042, RMRSEA of 0.113, TLI of 0.907, CFI of 0.923, and NFI of 0.910. However, the value of good-fitness indices was better when the adjusted model was tested. These values included: Cmin/df of 1.054, p-value of 0.366, GFI of 0.981, AGFI of 0.959, RMR of 0.017, RMRSEA of 0.012, TLI of 0.999, CFI of 0.999, and NFI of 0.990. Furthermore, the factor loadings, composite reliability, and average variance extracted from the analyzed variables were taken into account to explain unidimensional measurements; they were more than 0.05. [40]. All of the variables' related values are shown in Table 1.

Table 1. Factor Loading and convergent validity.

Variables	EXPPR	EXCOM	EXPER	CR	AVE
EXPPR1	0.733				
EXPPR2	0.867				
EXPPR3	0.872			0.983	0.836
EXPPR4	0.893				
EXPPR5	0.816				
EXCOM1		0.912			
EXCOM2		0.932		0.948	0.895
EXCOM3		0.840			
EXPER1			0.838		
EXPER2			0.916		
EXPER3			0.861		
EXPER4			0.846	0.958	0.850
EXPER5			0.810		
EXPER6			0.901		
EXPER7			0.775		

Note: EXPPR1–5 refers to export promotion program, EXCOM1–3 refers to export competitiveness, and EXPER1–7 refers to export performance.

From Table 1, the study revealed that all factor loadings from CFA were about 0.733–0.893 for the export promotion program, 0.840–0.932 for export competitiveness, and 0.775–0.916 for export performance. Meanwhile, the result also revealed composite reliability ranging from 0.948–0.983 and average variance extracted from 0.836–0.895. These values were more than 0.50, indicating that all variables can be studied further [40]. In addition, the correlation matrix and square root of AVE were considered for convergent validity and discriminant validity. Table 2 shows discriminant validity.

Table 2. Discriminant validity.

Variables	EXPPR	EXCOM	EXPER
EXPPR	0.914		
EXCOM	0.899	0.946	
EXPER	0.756	0.857	0.922

Note: EXPPR refers to export promotion program, EXCOM refers to export competitiveness, and EXPER refers to export performance.

From Table 2, the square root of AVE was higher than the correlation coefficient matrix of the variables, which correlation coefficients ranging from 0.756–0.899. In addition, the variance inflation factor (VIF) to inspect multicollinearity ranged from 2.179–4.631. This means that all variables, including export promotion program, export competitiveness, and export performance were identical and appropriate for further analysis.

3.3. Finalized Model and Hypothesis Analysis

After assessing convergent and discriminant validity using confirmatory factor analysis (CFA), the final model was created, and structural equation modeling (SEM) was used to test the hypothesis. Consequently, the final model was initially investigated, and its good-fitness indices were unacceptable since they did not meet the recommended criteria: Cmin/df of 6.138, p-value of 0.000, GFI of 0.830, AGFI of 0.765, RMR of 0.042, RMRSEA of 0.113, TLI of 0.907, CFI of 0.923, and NFI of 0.910. However, the model was modified based on the proposal of modification indices, and its good-fit indices were subsequently enhanced, Cmin/df of 0.874, p-value of 0.735, GFI of 0.984, AGFI of 0.966, RMR of 0.013, RMRSEA of 0.000, TLI of 1.000, CFI of 1.000, and NFI of 0.992 (see Figure 2).

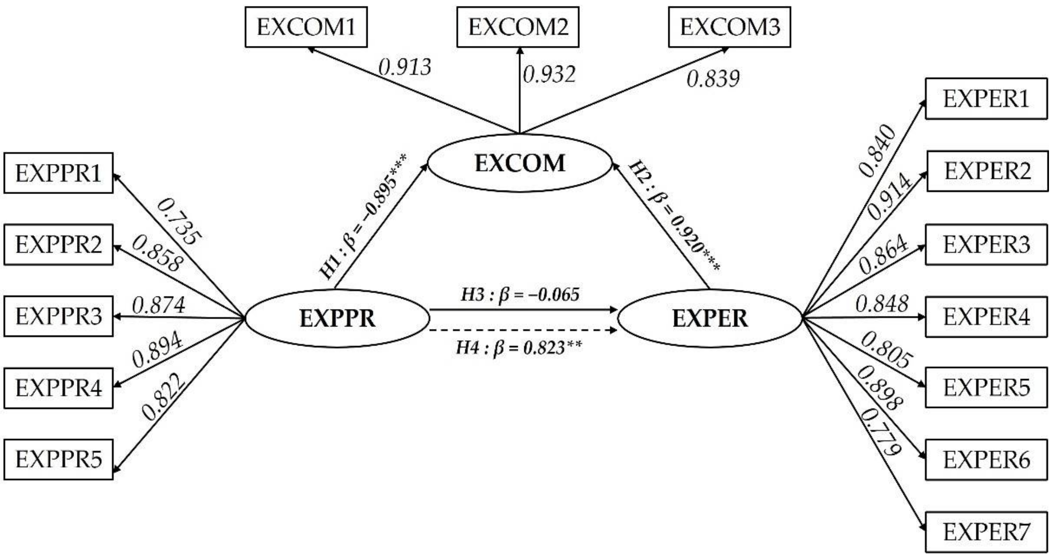

Figure 2. Finalized Model.

Table 3 shows the findings of the hypothesis investigation and the influence prediction ability on variables. Hypothesis (H) 1 showed that export promotion program influenced export competitiveness (β = 0.895, $p < 0.05$) while hypothesis (H) 2 implied that export competitiveness influenced export performance (β = 0.920, $p < 0.05$). Nevertheless, hypothesis (H) 3 revealed that the export promotion program did not influence export performance (β = −0.069, $p < 0.05$) at the statistically significant level of 0.001.

Table 3. Standardized Estimate, Unstandardized Estimate, Standard Error, *t*-value, *z*-value, and *p*-value.

Variables	Untandardized Estimate (b)	Standardized Estimate (β)	S.E.	*t*−Value	*p*−Value
H1: EXPPR → EXCOM	0.928	0.895	0.050	18.412	***
H2: EXCOM → EXPER	0.746	0.920	0.074	10.036	***
H3: EXPPR → EXPER	−0.055	−0.065	0.069	−0.800	0.424

Note: EXPPR refers to export promotion program, EXCOM refers to export competitiveness, and EXPER refers to export performance. *** *p*-value =< 0.001.

Table 4 indicates that the export promotion program in hypothesis (H) 4 had a significant indirect influence with a fully mediating role on export performance through export competitiveness since the *p*-value from bootstrapping technique was lower than 0.05.

Table 4. Mediating Effect Result.

Variables	IV-N-DV		Meditating Type
	Direct	Indirect	
H4: EXPPR → EXCOM → EXPER	−0.065	0.823 **	Full Mediation

Note: EXPPR refers to export promotion program, EXCOM refers to export competitiveness, and EXPER refers to export performance. ** *p*-value =< 0.01.

4. Discussion

The findings of the study reveal that export promotion programs influenced export competitiveness. This is because the government and related agency support programs such as financial and tax incentives, participation in trade fairs, export-related market research, export training, and export support and consulting can enable export entrepreneurs to obtain export competitiveness, including high product quality differentiation, and promotion effectiveness. They may use the government-provided consultancy, market information, and export training program to connect and develop the skills and abilities of their personnel so that they can successfully use organizational resources for their export efforts. This is consistent with the research conducted by Cuyvers et al. [28], who examined a decision support model for the planning and evaluation of export promotion activities by government export promotion institutions in the Belgian case and found that financial and tax incentives, trade fairs, market information, export training, and education, and export consultancy can help evaluate export promotion activities. Meanwhile, Freixanet and Churakova [16] express that export promotion programs in Russian manufacturers successfully achieve their objectives of enhancing firms' export marketing competencies by highlighting apparent issues regarding program awareness, availability, and accessibility-related to exportation. Export promotion policies in Cameroon were studied by Njinyah [29], who found that government policies for export promotion can create opportunities for entrepreneurs to gain competitiveness in terms of country and market specifications, knowledge of trade barriers in the export market, as well as the right marketing mix of the product. Finally, Catanzaro and Teyssier [30] indicate that export promotion programs might be linked to the development of export capabilities as well as the adoption of risk management methods. The study is also in line with the result of Mata et al. [31], who indicated that finance and marketing assistance might aid young entrepreneurial enterprises in overcoming the vulnerability of newness and smallness in acquiring competitive export capacities. To conclude with a discussion, the export promotion programs have a significant impact on export competitiveness.

In addition, the study result indicates that export competitiveness, including product quality, product differentiation, and promotion effectiveness influenced export performance regarding financial and market performance. This is due to the fact that the entrepreneurs' competitiveness in producing high-quality products that meet international standards and customer requirements as well as in offering product differentiation that specifically meets the unique customer demands and differs from competitors can be linked to export performance such as international operation improvement, profitability, sales volume growth, and international opportunity. According to the study, entrepreneurs' competitiveness in gaining promotion effectiveness—receiving direct promotion, exportation consulting, investment support, and enhancing marketing managers' international orientation—can also improve export performance from both a financial and market perspective. The study is consistent with the study conducted by Catanzaro and Teyssier [30], who demonstrate that export capabilities in managing international risk and implementing foreign direct investment strategies could better the international performance of small and medium enterprises. Furthermore, the findings of this research are in agreement with those of Keskin et al. [34], who indicated that unique company capabilities, comprising informational, relational, and marketing skills as well as differentiation and cost leadership, can offer export businesses a competitive edge in international markets and increase their export performance in foreign markets simultaneously. Accordingly, export competitiveness can be confirmed to have an impact on export performance.

Unfortunately, the findings revealed that the export promotion program did not influence export performance. However, the bootstrapping technique indicated that the export promotion program had a significant indirect influence on export performance. This is due to the fact that export promotion programs such as financial and tax incentives, participation in trade fairs, export-related market research, export training, and export support and consulting provided by the government and related export agencies are not enough to directly create export performance regarding international operation improvement, profitability, sales volume growth, and international opportunity. To link the export promotion programs to export performance, the entrepreneurs should be able to manage themselves to gain export competitiveness in creating high product quality, product differentiation, and promotion effectiveness. For this result, the study corresponds to the study carried out by Njinyah [29], who found the export policy from the government did not have a direct effect on export performance from both financial and non-financial perspectives, including the increased scale of business, return on investment, profit growth, and relationship with the stakeholder. In addition, the study is also consistent with Mata et al. [31], indicating that competitive capabilities play a significant role in mediating the relationship between marketing support from related institutions and the export performance of the enterprises. Lastly, the study is supported by Catanzaro and Teyssier [30], who also implied that export capabilities play a crucial role in the mediation between export promotion programs offered by the government and the international performance of the small and medium businesses.

The result of this study can be linked to have a managerial, theoretical, and political contribution. For managerial contribution, to create a satisfactory export performance for craft products exportation business, the entrepreneurs should be determined to create export competitiveness, including product quality, product differentiation, and promotion effectiveness by attempting to provide unique products differing from competitors with high product quality through utilizing direct promotion, information, consultancy, investment support, marketing managers' international orientation related to exportation. However, to create competitiveness among export enterprises, the entrepreneurs need support from the government, as depicted in the study result indicating that the export promotion programs provided by the government and relevant export agencies play a significant role in bettering export performance via export competitiveness. For the theoretical contribution, the study result can respond to the literature reviews to confirm that the export promotion program had a significant indirect influence with a fully mediating role on export performance through export competitiveness. For the political contribution, the government and relevant export agencies should emphasize providing the export promotion programs such as financial and tax incentives, domestic and international trade fairs participation, export-related market information, export training, and education, as well as export consultation. Since marine transport plays a significant role in the exportation of many countries, the government should also establish appropriate infrastructures such as electronic export clearance, the country's power supply, and others to benefit export performance.

Nevertheless, this study contains numerous limitations that can be linked to finding future potential research. Firstly, the study only focuses on examining the effect of export promotion programs on export competitiveness and export performance. There are numbers of related influential factors such as differentiation and niche strategy, alliances with international partners, or distribution effectiveness that are ignored. Therefore, future research should extend the study to cover other potential factors. Secondly, this study obtained data for analysis from only a single industry that is related to craft product exportation firms. Consequently, the future study can shift to other business sectors such as agricultural, industrial, electronic, or food and beverage products. Some of these are encountering export problems. Meanwhile, some of these have the potential to develop the national economy. Thirdly, the study aimed at revealing export competitiveness and export performance in general, ignoring the study on significant characteristics and barriers regarding the destination of the importers' country. Some literature reviews write that different importer countries require different requirements varying export competitiveness and export performance. Future research should perhaps be conducted on specified countries. Another point is that this study focused on overall transportation, which lacks the study of specific mode, especially the marine mode. Since marine transportation bears a significance to entrepreneurs and nations, future research should specify factors related to marine transportation to create export performance effectively. Lastly, this study is devoted to research analysis through a quantitative research approach. So, the other research approach, such as qualitative research orientation with different data collection and analysis techniques, was ignored. Consequently, future research adopting a qualitative research approach using interviews, observation, focus group, and others can be recommended.

5. Conclusions

This study of the impact of export promotion programs on export competitiveness and export performance of craft products aims to analyze the export promotion program, export competitiveness, and export performance using Structure Equation Modelling (SEM) to analyze the data from employees working in 46 exporting craft product companies in Thailand. The result indicated that export promotion programs, including financial and tax incentives, participation in trade fairs, export-related market research, export training, and export support and consulting, can influence the export competitiveness and export competitiveness including product quality, product differentiation, and promotion effectiveness can influence export performance in terms of international operation improvement, profitability, sales volume growth, and international opportunity. However, the study indicated that an export promotion program does not have a direct influence on export performance, but it has an indirect impact on export performance through export competitiveness. In other words, export competitiveness mediates the relationship between export promotion programs and export performance. Due to the study findings, managerial, theoretical, and political contributions can be remarked. For managerial contribution, the study suggests that entrepreneurs focus on product quality, product differentiation, and promotion effectiveness by producing unique products with high quality. As regards the theoretical contribution, the literature reviews related to the relationship among export promotion programs on export competitiveness and export performance of craft products can be firmed. As for the political contribution, the study reveals that the government should set the policy to promote export promotion programs, including direct promotion, knowledge and information sharing, consultancy, and investment support. In addition, the discussion of this study can contribute suggestions to marine transport, which is one of the critical international entry modes used by many businesses to expand businesses. Ultimately, shipping cost savings are related to export efficiency. However, the study has some limitations related to the variables, study area, and research methodology. Therefore, it is recommended that future research focuses more on potential variables that can influence the export competitiveness, extending the study area to other products as well as utilizing other research methods, such as a qualitative approach.

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Scientific Mapping of Coastal Governance: Global Benchmarks and Trends

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Abstract: This research panoramically and empirically reviews the scientific production on coastal governance studies, mapping global networks of countries, organizations, authors, themes, and journals as referents for this topic. The articles were examined through a bibliometric/scientometric approach based on 2043 articles corpus stored in the Web of Science (JCR), applying the bibliometric laws of Price, Lotka, and Zipf to add further validity to the use of VOSviewer for data and metadata processing. The results highlight an uninterrupted exponential increase in publications since 1991, with a high concentration in 29 countries (21%), 461 organizations (18%), 99 authors (1.45%), and 4 growing journals (1%). The emerging topics observed in the literature are related to coastal sustainability and coastal management. Complementing previous studies on coastal zone management and marine territorial planning, we add coastal systems governance as a topic.

Keywords: coastal management; fishing areas; spatial planning; coastal environmental; coastal geopolitics; blue economy; bibliometrics

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1. Introduction

This article aims to provide an empirical and panoramic overview of the worldwide scientific production on coastal governance. We understand coastal governance to be a system that integrates and manages the complex contexts that exist in the coastal zone to support decision making, based on policies, programs, and regulations, encouraging the participation of stakeholders in achieving sustainable development objectives. Coastal governance implies confronting problems, most of which are difficult problems without a technical solution; at this point, the political process of decision making is a key point in the system and relates to other systems of knowledge, in adjustment with a national or international normative framework. All these considerations put coastal governance into a policy framework: the action of the state and the diversity of actors. Thus, coastal governance encompasses not only the actions of the national/local state but also those of other actors, such as communities, businesses, and civil society organizations, starting with policy problems related by these different actors, their solutions, the decision making, the implementation, and the achievement of those solutions [1–4].

Coastal governance is a topic that has become increasingly important due to the growing interaction between productive activities, commercial flows, habitability in coastal zones, and their effects on the ecosystem [5–10], which has forced the incorporation of participatory and collaborative processes in territorial management and governance [11–16]. The growing interest from the scientific community in the coastal governance phenomenon is reflected in the increase in the articles published in journals indexed in the Web of Science (WoS) databases in the last fifteen years, highlighting research generated in countries, such as Australia [14,17], Canada [18,19], and the USA [20,21].

To achieve the research aims, bibliometric/scientometric methods were used to address questions, such as: What is the evolution of scientific production in recent decades on research on coastal governance? What is the geographical and organizational distribution of research on coastal governance? Which authors are the main researchers on coastal governance? Which journals on coastal governance tend to be more influential for scientific production?

1.1. Fisheries Management and Coastal Governance

Climate change, marine habitat pollution, and indiscriminate fishing are rapidly affecting the marine environment; therefore, governments are intensifying measures to mitigate these effects and promote sustainable development [22–25].

Among these measures, Marine Protected Areas (MPAs) have had a positive effect on conservation processes around the world, through co-management between public and private entities, considering a collaborative strategy, technological introduction, aquaculture development, and tourism promotion [7,8,26]. The challenges presented by Marine Protected Areas are to have guidelines for conflict resolution, organizations' rights recognition, and integration of values and local culture, seeking a balance between the different stakeholders and their own interests and vulnerabilities [11,13,27,28]. Among the weaknesses encountered are clashes between the organizations and the public sector, the lack of rules for co-management between the state and the beneficiaries, instabilities in power groups, ideological, cultural, and political differences, and disagreements between national and local actors [25,29].

Another approach for coastal territories' sustainability has been the implementation of integrated management focuses [12,30,31]. This approach promotes management decentralization, municipal governance power, cooperation with local academic institutions, and civil society participation to achieve resource conservation and preserve the local identity and cultural heritage [32–34]. However, the challenges include securing property rights in small-scale coastal fisheries, stopping illegal fishing, and limiting environmentally damaging fishing equipment, fostering the organizations' empowerment, a balance in co-management, and the internalization of biodiversity conservation [35–37].

Finally, ecosystem-based assessments help to reduce uncertainty in resource inventories and provide ecological functional indicators, allowing for flexible policy integration, social and ecological justice, collaborative governance, and local autonomy over coastal resource management [38–43]. To achieve effective long-term protection, conventional and centralized conservation approaches are not sufficient [9,44]. Challenges in marine ecosystem planning include resource scarcity management, scientific uncertainty, policy design to promote species conservation and recovery, coordination among the activities and practices of the various actors in planning, sensitivity to climate-change-driven species redistribution, and improving social connectedness [4,14,45–49].

1.2. Policies of Coastal Governance

Researchers have used various terms, such as agency, incentives, governance, environmental management, and systemic complexity, to refer to the policy concept. Agency has been treated as the work of actors in the creation, maintenance, and disruption of organizational practices [10,50], associated with the collaboration and participation of the actors involved in these processes, identifying collaborative structures and substructures, generally referred to as collaborative networks whose policy outcomes will depend on the characteristics of these structures and substructures.

Co-management has been used by authors, such as Marin et al. [51] and Linke et al. [52], when referring to the multiplicity of actors that optimize the management of resources and social capacities that allow the forms and functions of adaptive organizational systems to be modified in contexts of adaptive and sustainable governance. Co-management recognizes the multiplicity and types of actors that relate and interrelate [10,51,53] in the planning and implementation processes related to adaptive strategies and interactions that tend to occur at the local level [53], noting the relevance of participatory processes to balance sustainability with survival, community development, and urbanization [54].

Other studies have noted the agency difficulties, such as the institutional fragmentation and constant change processes [15], the identification of dense collaborative substructures, with an increasing specificity and complexity of collaborative links [10], the integrated agency paradox [50], the diversity of rationalities involved [19], as well as the coexistence of conflicting preferences in coastal management in the face of various climate scenarios [54].

Economic incentives and coastal economic, social, and territorial transformations are other aspects that research has examined, addressing the economic incentives and fiscal reform effects on land development [55], the local public finance effects, urbanization, economic policy transformation [56], compensation policies in land acquisition processes, and new problems, such as displaced people [57]. This shows the relevance of financial management in policies involving coastal land use.

The governance concept has been linked to participatory and collaborative policy processes, as evidenced when referring to the work of actors and the legitimacy of practices in territorial management [50] or polycentric multistakeholder governance at various scales that exceed the state [58]. This can be related to local governance levels [53], governance practices [59], the regional approach to maritime governance in the pan-European context [15], ecosystem services governance [19], marine/maritime spatial planning (MSP), as an approach involving an adaptive ecosystem-based approach [42], and Integrated Management (IM) of coastal and marine activities [14].

Likewise, challenges emerge for environmental governance and restoration, marine and coastal environments [60,61], and environmental governance [17]. Forms of rescaled environmental governance have been identified [17], which, in some cases, would lead to their identification as pendulum swings [17]. These challenges could give way to adaptive governance, sustainable resource management [52], and a blue economy (BE) [62].

This has been associated with a systemic spatial complexity and the interests of different actors, identifying multifaceted problems that require complex arrangements [63], a conflicting spatial competition between economic, maritime, and biodiversity activities that can lead to the fragmentation of policies, private initiatives, and regulations [15]. The vulnerability of coastal regions is an open question for coastal use, linked to coastal tourism governance and other land uses [64,65]. A particular challenge has also been observed in local governments in the face of little or no adequate international governance in response to climate change, ecosystem integration, and the establishment of systemic governance [16].

Environmental management has gained relevance in studies associated with policies, identifying terms related to: watershed approach [17], the combination of complex nature and coastal uses [64], ecosystem-based management (EBM), as an integral approach to improve the environment and collaborate on public policies and public administration [10], ecosystem service use improvement to increase human well-being [19], long-term uncertainty in the face of climate change risks and its impacts [54], the coastal zone's characterization as a complex socioecological system [66], the focus on poor people in access to coastal resources [67], territorial use rights for small-scale fisheries [68], ecosystem service classification and adaptation to vulnerability [69], and finally, the linkage with the Sustainable Development Goals [62].

2. Materials and Methods

The method used was oriented to scientific measurement, based on documented scientific research, according to bibliometric laws. Scientometrics as a kind of meta-analysis [70] focuses on studying what, how much, when, who, and where knowledge is produced [71], and it is a method recently used in subjects related to this study [72–81].

A set of articles were extracted from the Web of Science Core Collection (WoS), using the databases: the Science Citation Index Expanded (SCIE) with 178 indexing categories and the Social Sciences Citation Index (SSCI) with 58 indexing categories; both indexes were included in the Journal Citation Report (JCR-WoS) and conformed to high-quality journals, whose impact is calculated annually based on the average citations received. These articles were identified with the search vector TS = (Coastal AND Governance), using the topics field label (TS), Boolean operator (AND), and simultaneously incorporating the concepts of coastal and governance. Time restrictions were left free, to the date of extraction (29 September 2021) from the year 1900 for SCI-E and 1956 for SSCI, the restrictions on access to the WoS database. [82].

The annual growth of research publications on the recovered article set was examined based on the Price Law [83,84], searching for possible exponential growth, based on the annual number of published articles and the adjusted coefficient of determination (R-squared) for the exponential growth rate of these publications over time. For data and metadata analysis, VOSviewer (CWTS—Leiden University, Leiden, The Netherlands) [85] was used, as well as the bibliometric laws of: (1) Lotka to identify the prolific authors set with the highest number of published articles on the coastal governance topic, a set estimated by the square root of the total authors contributing to the article set analyzed [86]; the author identification process by VOSviewer, based on the database extracted from WoS, incorporated the total of authors registered as data and metadata for each article analyzed; and (2) Zipf, which recognizes the exponential decrease in the use frequency of words inside a knowledge corpus [87–89]; therefore, there are words that are used very frequently and others that are present in the literature rarely. This law was applied in this case for the empirical determination of the keywords plus metadata incorporated in the database extracted from WoS with the highest occurrence frequency in the total set of articles studied [90].

3. Results

The 2043 articles on coastal governance, extracted on 29 September 2021, presented a temporal exponential growth, with an R^2 of 89.96% between 1991 and 2021, excluding, in this adjustment, one isolated article published in 1978 (see Supplementary Material Table S1: CGv2.txt to be read with bibliometric software and a spreadsheet_CG.xlsx for standard use). This accounted for an overall critical researcher mass, interested in increasing the knowledge corpus on this topic. In addition to this, the temporal distribution of the 2043 articles published on coastal governance in 386 JCR-WoS journals is presented in Figure 1.

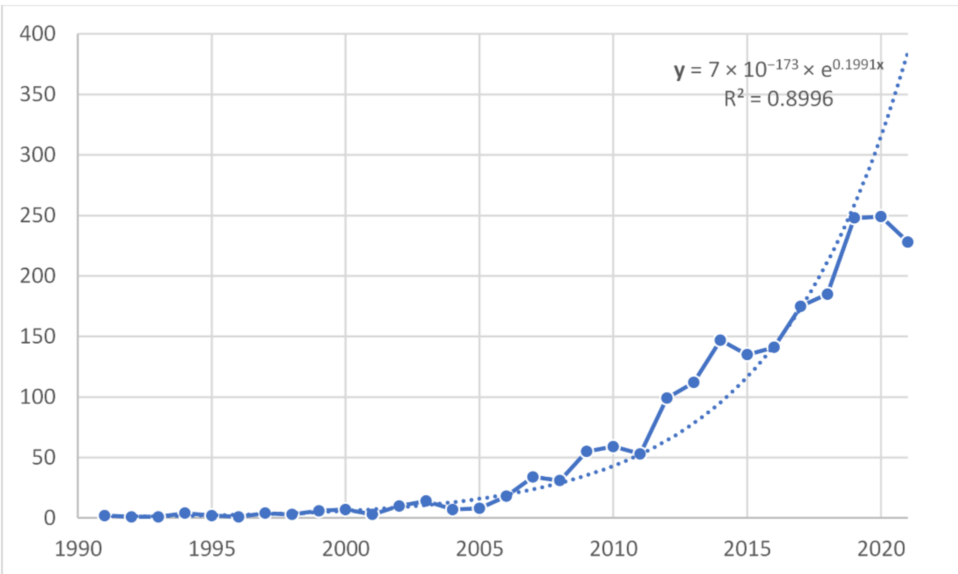
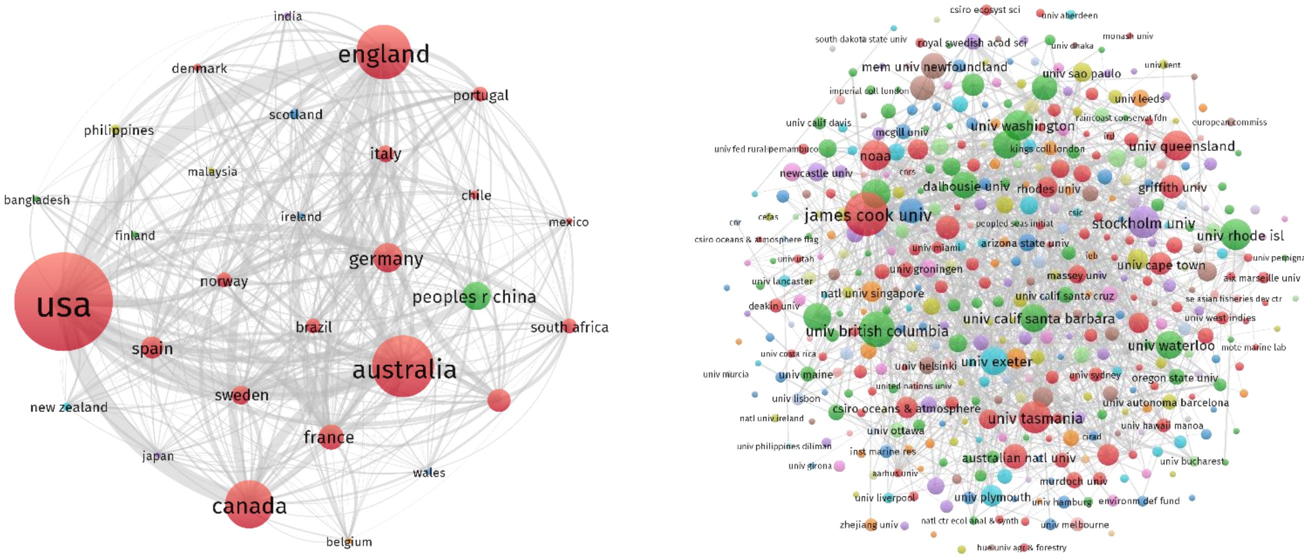


Figure 1. Publication time series and trend on coastal governance.

3.1. Global Scientific Benchmarks in Coastal Governance Studies

At the global level, the contribution of countries or territories to the scientific production documented on coastal governance studies in JCR-WoS journals varied from one country or territory to another, with their contribution commonly being at low-production levels. In this way, it was possible to identify the global referents for exceeding the average of the geographical set.

Above the average global contribution, 29 countries or territories were identified as contributing 28 or more articles, and 461 organizations contributed 3 or more articles (see Figure 2). Other background information provided by the descriptive analysis was the high atomization of scientific production by territory and institution, corroborated by mode 1 (see Table 1, mode) and the variation coefficient that gave us a value of 2.38 for the territory and 1.76 for the organizations, confirming high variability. The distribution of the data was represented by a leptokurtic curve (see Table 1, kurtosis), which indicated that most of the data were concentrated around the mean and with a higher concentration above the mean, as indicated by the skewness coefficient (see Table 1, skewness).



(**a**) (**b**)

Figure 2. Co-authorship networks. (**a**) Co-authorship at a national level. (**b**) Co-authorship at an organizational level (1978–2021).

Table 1. Descriptive statistics of territorial and organizational contribution to coastal governance studies (1978–2021).

Statistics	Country/Territory	Organization
Mean	27.02	2.28
Standard error	5.52	0.08
Median	5	1
Mode	1	1
Standard deviation	64.41	4.01
Variation coefficient	2.38	1.76
Kurtosis	26.69	64.76
Skewness coefficient	4.69	6.74
Minimum	1	1
Maximum	503	69
Count	136	2587

Figure 2a highlights countries/territories, such as the USA, Australia, England, and Canada, with over 250 published articles (see Table 2, rank A). Figure 2b highlights organizations, such as James Cook University, the University of British Columbia, Stockholm University, and the University of Tasmania, with over 40 articles (see Table 2, rank B).

Table 2. Main global references to territorial and organizational contribution on coastal governance studies (1978–2021).

Rank A	Country/ Territory	Articles	Contributionto 2043	Average Citations	Rank B	Organization [1]	Country/ Territory	Articles	Contribution to 2043	Average Citations
1	USA	503	25%	31	1	James Cook Univ	Australia	69	3%	38
2	Australia	318	16%	31	2	Univ British Columbia	Canada	48	2%	36
3	England	283	14%	35	3	Stockholm Univ	Sweden	42	2%	72
4	Canada	251	12%	25	4	Univ Tasmania	Australia	41	2%	18
5	Germany	153	7%	20	5	Univ Rhode Island	USA	39	2%	33
6	Peoples R China	147	7%	12	6	NOAA [2]	USA	37	2%	52
7	France	132	6%	20	7	Univ Queensland	Australia	37	2%	17
8	Netherlands	121	6%	28	8	Univ Washington	USA	37	2%	41
9	Spain	116	6%	27	9	Duke Univ	USA	35	2%	41
10	Sweden	100	5%	39	10	UC Santa Barbara	USA	33	2%	71

[1] Names used according to the data in the WoS database. [2] Considering 12 other forms of NOAA affiliation, 17 additional articles were reported in this period (NOAA Fisheries, NOAA Int Sect Off Gen Counsel, NOAA Marine Natl Monuments Program, NOAA NCEI, NOAA NMFS, NOAA NOS, NOAA Ocean Initiat Program, NOAA Papahanaumokuakea Marine Natl Monument, NOAA Scientist Emeritus, NOAA Southwest Fisheries Sci Ctr, NOAA Star, and NOAAs Off Natl Marine Sanctuaries).

Table 2 details the contribution to the 2043 documents on coastal governance. The top ten countries contributing to the production of these papers participated in authorship or co-authorship in over 5% of the total articles published, with the USA (25%) and Australia (16%) being the major contributors overall. This is reflected at the level of the top ten organizational contributions, with five affiliation organizations from the USA (Univ Rhode Island, NOAA, Univ Washington, Duke Univ, and UC Santa Barbara) and three affiliation organizations from Australia (James Cook Univ, Univ Tasmania, and Univ Queensland), with James Cook Univ as the organization with the highest global contribution in Australia, with 3%, given its participation in 69 articles.

Finally, with respect to individual authors who manage to be referents for their level of scientific production on coastal governance (1978–2021), of the 6826 authors identified according to Lotka's law, the prolific authors should be approximately 83 (= sqrt (6826)); we chose to recognize 99 of them with a production of five or more articles (up to 20 were observed) for the period studied. These 99 authors were adjusted to 98 by merging the WoS records of the authors: Bennett, Nathan J. (10 articles), and Bennett, Nathan James (6 articles).

Figure 3 allows us to identify, in the larger nodes, the authors who, among 98 cases, presented a much higher number of publications. The authors who were at the second concentration level (sqrt (98) $\approx$ 10) are detailed below. When considering 10 authors, this was equivalent to a scientific production level of 10 publications within the article set analyzed (see Table 3); therefore, 12 authors were considered to include all authors who had published at least 10 articles.

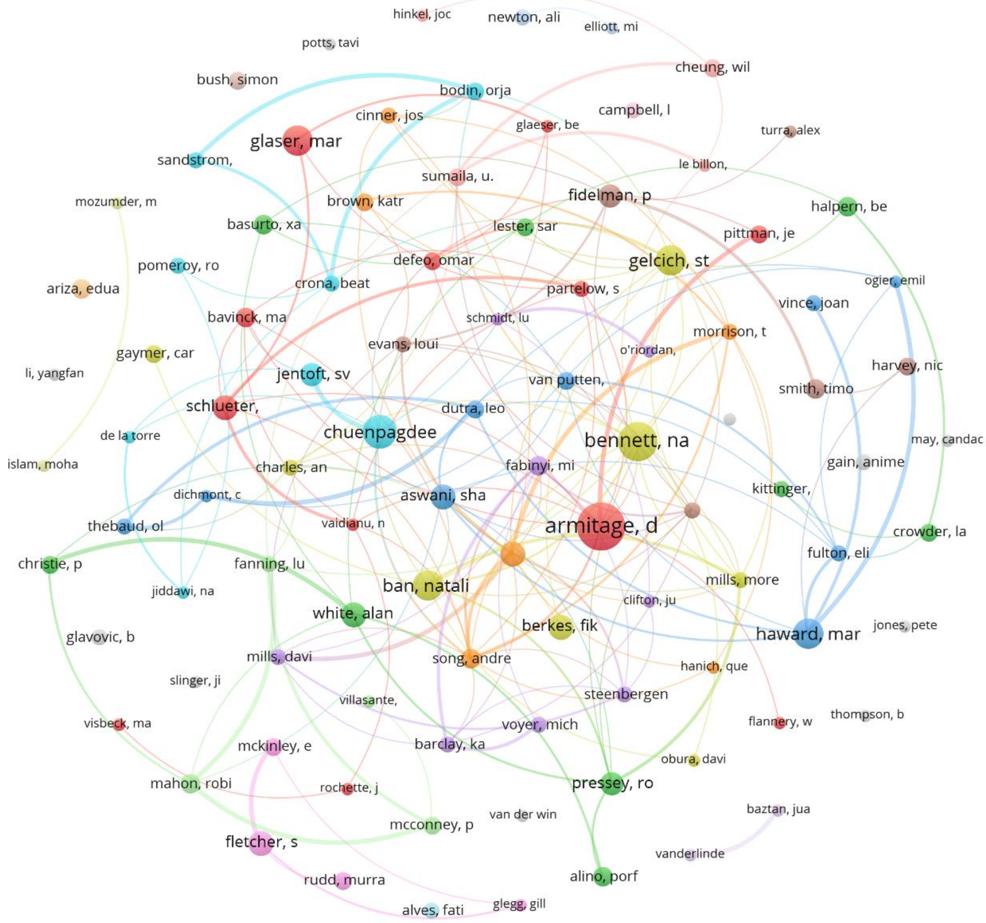


Figure 3. Co-authorship network, main researchers.

Table 3. Authors with the highest production in the co-authorship main researcher network.

Author	Network	Articles	Average Citations	Institutional Affiliation
Armitage, Derek	Red	20 *	12	Univ Waterloo, Canada
Bennett, Nathan J.	Yellow greenish	16 *	60	Univ British Columbia, Canada
Chuenpagdee, Ratana	Violet	14 *	46	Mem Univ, Canada
Ban, Natalie C.	Yellow greenish	12	25	Univ Victoria, Canada
Gelcich, Stefan	Yellow greenish	12	73 **	Pontificia Univ Católica Chile, Chile
Glaser, Marion	Red	12	21 **	Univ Bremen, Germany
Haward, Marcus	Green	12 *	27	Univ Tasmania, Australia
Aswani, Shankar	Green	10	28 **	Rhodes Univ, South Africa
Berkes, Fikret	Yellow greenish	10	39	Univ Manitoba, Canada
Cohen, Philippa J.	Orange	10 *	32	James Cook Univ, Australia
Fletcher, Stephen	Lavender	10 *	24	Univ Plymouth, England
Schlueter, Achim	Red	10	13	Jacobs Univ Bremen, Germany
White, Alan T.	Blue	10 *	66	Tetra Tech, Indonesia

* Co-author with the highest publications in their network. ** Co-author with the highest average citations compared to other co-authors in their network.

3.2. Scientific Trends in Coastal Governance Studies

Researchers from new countries are joining the discussion on coastal governance given the large number of new territorial affiliations shown in Figure 4 in yellow, orange, and red.

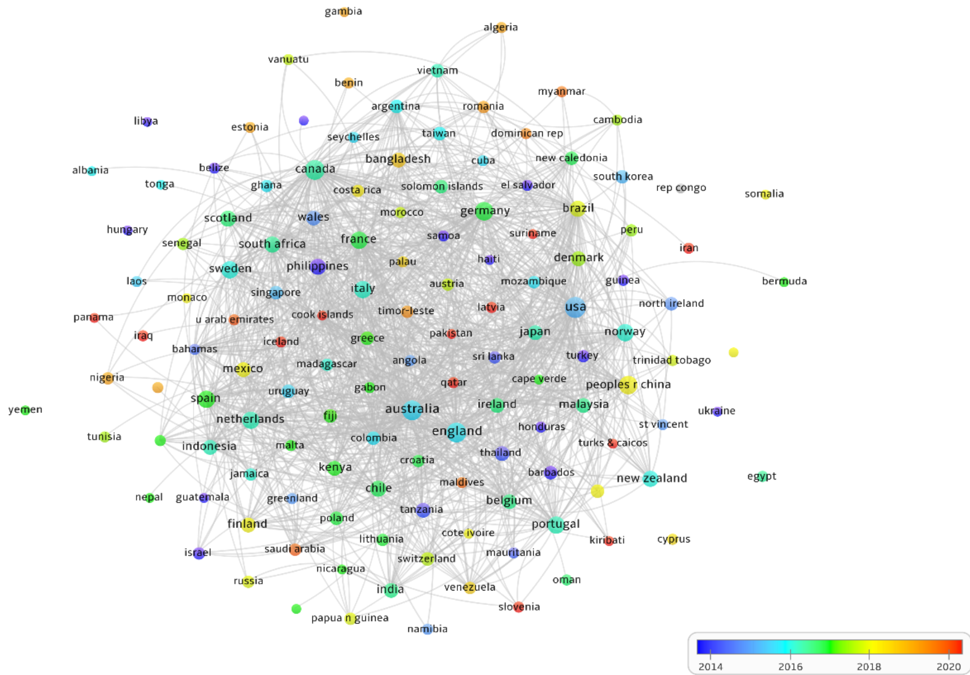


Figure 4. Temporal national co-authorship network.

For the 2974 keywords plus identified by Clarivate (WoS proprietary company), 1887 plus keywords only had one occurrence, and, in general, its exponential decrease fits a power regression (see Appendix A). There were 53 most relevant keywords plus according to Zipf's Law with 33 or more occurrences (sqrt (2974) = 54), from 33 (state, adaptive governance, and areas) to 590 (governance) occurrences. We highlighted several concepts used more recently, as shown in Figure 5 in red (values expressed in average years of publication), among them, some specific terms, such as (number of occurrences in parentheses): challenges (113), climate change (218), communities (46), ecosystem services (68), impact (56), perceptions (44), risk (49), sea-level rise (60), and vulnerability (125).

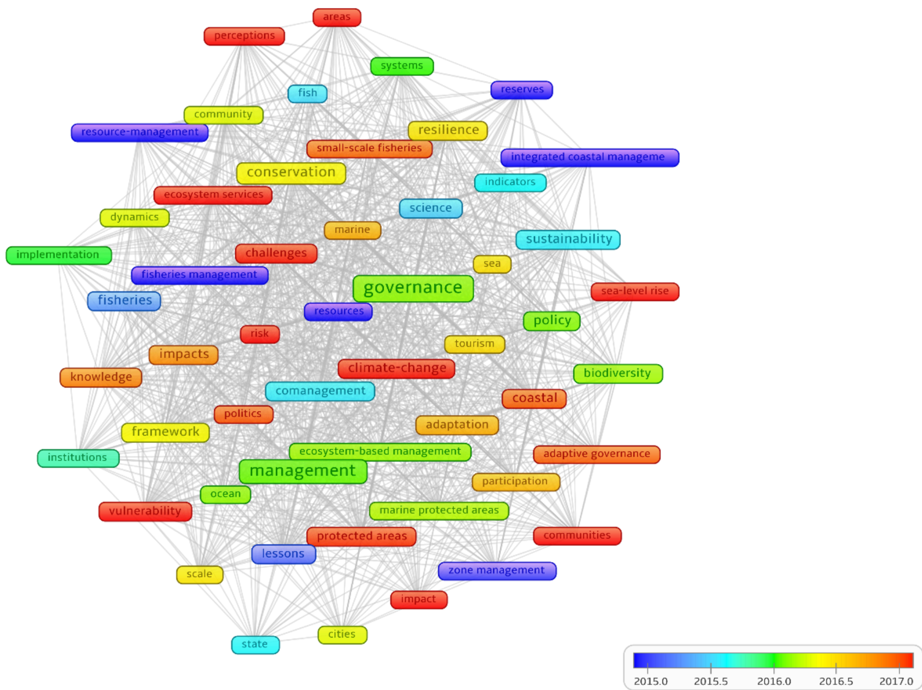


Figure 5. Keywords plus temporal co-occurrence graph.

More recently used concepts (mean publication year: 2017), such as ecosystem services (68 occurrences), communities (46), sea-level rise (60), protected areas (86), climate change (218), and a set of concepts thematically related to vulnerability (125), challenges (113), risks (56), and impacts (49), appear in the figure; the frame label size reflects the occurrence level, and the lines indicate the simultaneous use in articles or co-occurrence.

Figure 6 shows the concentration of publications on coastal governance studies between 2002 and 2021, the period in which 2008 (98%) of the 2043 articles were published, in the journals Marine Policy and Ocean Coastal Management. However, there is a notable increase in the number of publications in the fully open access journals Frontiers in Marine Science and Sustainability. Table 4 shows some of the characteristics of these four journals.

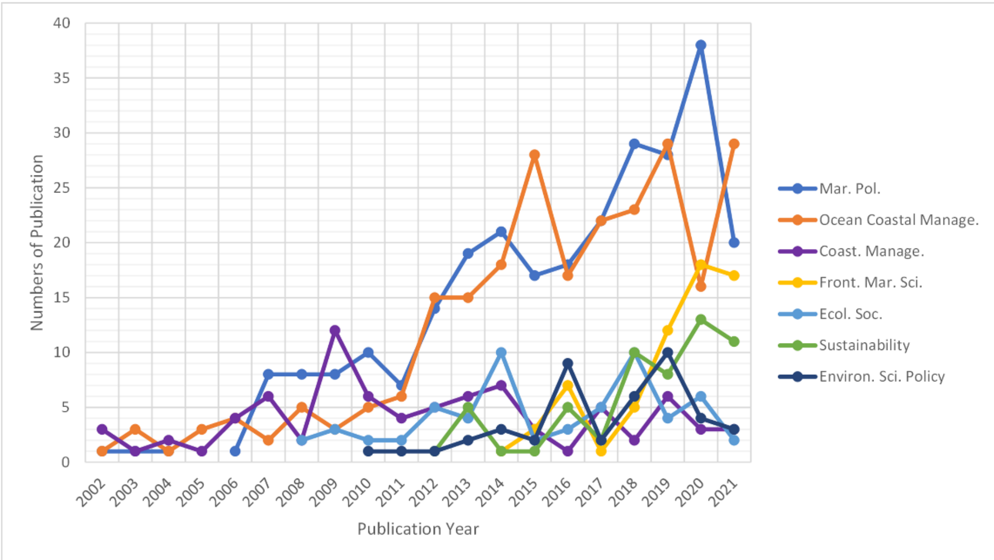


Figure 6. Journal publication trends (last 20 years).

Table 4. Journals with the highest numbers of publications in the journal trends.

Journal	WoS Categories	Publisher	IF (2020)	Best Quartile (2020)	Published Articles						
					2017	2018	2019	2020 *	2021 *	Total OA **	Total
Mar. Pol.	Environ. Stud.; Int. Relat.	Elsevier (Oxford, ENG)	4.173	Q1	23	29	28	38	40	59	158
Ocean Coastal Manage.	Oceanogr.; Water Resour.	Elsevier (Oxford, ENG)	3.284	Q1	23	23	29	16	39	30	130
Front. Mar. Sci.	Environ. Sciences; Mar. Freshw. Biol.	Frontiers Media (Lausanne, CHE)	4.912	Q1	1	5	12	18	23	59	59
Sustainability	Green Sustain. Sci. Technol.; Environ. Sci.; Environ. Stud.	MDPI (Basel, CHE)	3.251	Q2	2	10	8	13	17	50	50
Total, selection	4 journals				49	67	77	85	119	198	397
Total, journals *	441 journals				198	224	315	316	356	692	1409

* Data updated from WoS on 27 March 2022. ** Articles published with open access (reading access fees covered by the authors).

From Table 4, we can observe that these main journals that cover coastal governance studies belong mainly to the first quartile in their respective WoS categories, given that their impact factors (2020) fluctuated between 3251 and 4912, and the set of articles with open access was close to 50% of the total publications [91,92]. The highest impact factor (2020) corresponded to the journal "Frontiers in Marine Science", and thematically, the categories converged mainly to Environmental Studies and Environmental Sciences, although with double indexing variants that fluctuated between science, technology, and international politics.

4. Discussion

This article allows for the analysis of coastal systems studies from a management and political decision-making perspective and is, therefore, in line with previous bibliometric work by Birch et al. [93] on coastal zone management and Chalastani et al. [94] on marine spatial planning. However, given the breadth of the term governance, it can also approximate specific bibliometric analyses on estuarine system aspects [95], flood vulnerability [96], and coastal biogeochemistry [97].

The analysis was based on a set of 2043 articles analyzed from 386 journals, and their data and metadata were above the range (318 to 1316 articles from 118 to 309 journals) of other related bibliometrics identified [94–96]; in the case of Birch et al. [93], their sampling was even broader (5461 articles from 891 journals) by covering a topic as extensive as coastal zone management. The work by Gattuso et al. [97] seems, to us, to be an exception by adding terms in an inclusive way (with OR Boolean operators) to cover the broad spectrum of 14,743 articles in coastal biogeochemistry. Moreover, the authors' coverage analyzed (6826) was higher than those reported in other papers [94,95], although this figure depends on the co-authorship customs of each discipline and journal. Finally, VOSviewer was used as data and metadata analysis software, the same choice as other related bibliometrics [94,95], although, in general, this type of analysis is supported by specialized software [94,96] or specific Rstudio packages [93,95]. Moreover, we see the use of bibliometric laws, in this case, Price [86,87], Lotka [89], and Zipf [90], as a value in favor of this article to provide a methodological contribution to coastal governance studies.

The results reported with publication time series were subjected to growth adjustments, with R2 values from 83.89% to 94.49%, showing adjustments with respect to quadratic [93,95] or exponential functions [94]; in this respect, we were inclined to an exponential adjustment reporting values in that range [98]. Moreover, the use of Lotka's law [89] allowed us to incorporate, as an additional value, objective, and replicable criteria for the selection of prolific authors, which was also achieved for the establishment of relevant plus keywords by means of Zipf's law [90]. The countries with the highest production (USA, Australia, England, and Canada) were also reflected in the results reported in other related bibliometrics [93–95,97], and in the case of the reference journals identified in Table 4, there was agreement with the case of Marine Policy [93,94], Ocean & Coastal Management [93,94], and Frontiers in Marine Science [94]. The same was also true in the temporal publications that we presented in this article, although in some cases, this information was only partial [93]. Thus, our article complements previous studies on coastal zone management and marine territorial planning by providing knowledge on coastal governance research, so far identified in bibliometric studies only at the marine governance [93,94] and ocean governance [94] levels.

5. Conclusions

From the present coastal governance bibliometric study, we can conclude that, based on the research questions and on empirical evidence gathered from three decades of study, coastal governance is evolving positively at an exponential growth rate, allowing the generation of an ever-greater volume of knowledge on this topic.

As for the territorial contribution to scientific production, the 2043 articles studied were the result of the interconnected effort made by authors from 136 countries/territories; several of these were new contributors, but in total, they contributed an average of 27 articles in these thirty years, and in 10 cases, they made at least 100 contributions, with authors from the USA, Australia, England, and Canada standing out with more than 250 articles.

At the organizational level, there were 2587 contributors with 2 to 3 articles on average, but with peaks reaching 69 publications in the case of James Cook University (Australia), followed by the University of British Columbia (Canada), Stockholm University (Sweden), and the University of Tasmania (Australia). This serves as context for the identification of 12 prolific authors with a contribution of the publication of 10 to 20 articles, some linked to the universities of James Cook, British Columbia, and Tasmania, and with links to the reference countries Australia (two cases), Canada (five), England (one), and Germany (two) but also highlighting authors from Chile, Indonesia, and South Africa.

This research was published mainly in a group of four journals, which gathered a third of the scientific production analyzed in coastal governance (683 articles), marking a growing trend in publications on this topic, a situation that is also being recognized by other contemporary bibliometrics in the marine and coastal management fields, with 50% of articles now published in open access format. New thematic trends include emerging concepts related to coastal sustainability (ecosystem services, communities, sea-level rise, protected areas, and climate change) and coastal management (vulnerability, challenges, risks, and impacts).

Potential limitations were the lack of greater depth in specific coastal governance areas, such as fisheries and policy areas, aspects that we considered in a general way. However, we opted for taking a less classical and more panoramic viewpoint in search of new trends, such as those observed.

In terms of future research, it seems relevant, from a scientometric perspective, to delve into the marked trend towards open access publications in the four most prolific journals and how this could improve their citation value rates, author prominence, and core and peripheral mobility. From the thematic implication of coastal governance, there are scale challenges in analyses at the ocean governance and port governance levels that can be explored and related to our findings. Moreover, the disciplinary interfaces with the economy in terms of the blue economy [76] and, at the geopolitical level, their impacts are other variants to be explored [99].

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/jmse10060751/s1, Table S1: CGv2.txt, Table S2: spreadsheet_CG.xlsx.

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Appendix A. Zipf Law

This appendix presents the outcomes of fitting keyword plus usage occurrence to a power regression ($y = ax^{\beta}$).

Table A1. Model Summary *.

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.970	0.940	0.940	0.228

* The independent variable is ID.

Table A2. ANOVA *.

ANOVA	Sum of Squares	df	Mean Square	F	Sig.
Regression	2416.222	1	2416.222	46,385.232	0.000
Residual	153.406	2945	0.052		
Total	2569.628	2946			

* The independent variable is ID.

Table A3. Coefficients *.

Coefficients	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
ln(ID)	−0.911	0.004	−0.970	−215.372	0.000
(Constant = a)	1006.893	30.087		33.466	0.000

* The dependent variable is ln(occurrences).

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Risk Assessment of Navigation Safety for Ferries

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Abstract: This study aims to discuss a risk assessment of navigation safety for ferries. In this research, the risk factors (RFs) for the navigation safety of ferries are first investigated from relevant literature and ferry operational features. A fuzzy AHP (Analytic Hierarchical Process) approach is then proposed to weight those RFs, after which a continuous risk-matrix model is then developed to determine the RFs' risk levels. Finally, to validate the practical application of the proposed model, ferries traveling across the Taiwan Strait were empirically investigated. The results may provide practical information for ferry operators to improve their safety performances. Further, the proposed risk assessment approach may provide references for related research in the safety management of short-distance passenger ships.

Keywords: ferry; navigation; safety; risk; fuzzy AHP

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1. Introduction

Throughout the history of human development, sea transport has been widely exploited for the movement of passengers and cargo in many nations, especially in archipelagic countries. Although sea passenger transport has gradually diminished over the past two decades [1], in part because of rapid developments in aviation and road transport, passengers continue to use cruises or ferries as the main means of transport for different purposes [2].

Generally, cruise ships operate long-distance international routes, and their main functions are to provide passengers with leisure travel and sightseeing needs. Therefore, in design, the size of a cruise ship is usually larger and the requirements for entertainment facilities and comfort are generally more important than speed, whereas a ferry, also known as a traffic ship, is a regular multifunction ship for passengers and cargo. Its main function is to carry passengers, goods, and vehicles (including land vehicles and trains) between islands across short distances. Furthermore, the ferry is also known as a mass transportation system for islands and cities located by the water. For transportation between two points, the cost of a ferry is significantly lower than that of building bridges or tunnels. Nonetheless, one of the disadvantages of ferry transport is that it could be easily suspended due to weather conditions.

In practice, the primary requirement of passenger transport by ferry is travel speed [3]. Thus, in ship design, a ferry's tonnage is relatively small compared to that of a cruise vessel. In addition, the requirement for speed is much more crucial than comfort and entertainment facilities. Furthermore, in terms of safety facilities for maritime navigation, the requirements of cruise ships are much greater than those of ferries. Generally, cruise ships not only have diversified professionals and a variety of life-saving equipment but also have a certain number of specifications for the prevention of maritime accidents and for personnel training [4]. By contrast, for ferries, except for basic rescue and escape equipment, the safety management activities are relatively inadequate compared with cruise ships. Furthermore, due to the features of short-distance traffic, in practice, operators may easily neglect the SOPs (standard operational procedures) for safety navigation. As a result, although governments have enforced stricter regulations, many fatal ferry accidents still occur relatively frequently.

Globally, calamitous accidents with many casualties and injuries pertaining to ferry transport have been reported. For instance, at least 60 people drowned after an overloaded ferry capsized in the river in the DR Congo in February 2021 [5]. Another deplorable incident happened in Bangladesh in April 2021 when an overcrowded ferry collided head-on with a cargo ship, leading to a total of 34 deaths [6]. In addition, the number of reported ferry accidents raises concerns about navigation safety management for ferry transportation. For example, South Korea documented at least 110 ferry accidents between 2015 and 2019, although its government has implemented coastal ferry safety innovative strategies since September 2014 to avoid maritime disasters, such as the sinking of the MV Sewol, resulting in a death toll of 304 passengers and crew members in April 2014 [7]. For Taiwanese maritime navigation, a total of 583 ship accidents occurred between 2014 and 2019 for some key reasons: collision (33.22%), striking (15.18%), machinery failure (10.16%), grounding (8.56%), and fire/explosion (1.37%) [8].

Additionally, the proportion of navigation accidents is currently on the rise in several countries. More specifically, about 37.5% of accidents involving passenger vessels, including ferries, were recorded in Bangladesh between 2008 and 2019 [9]. Furthermore, the potential risks concerning the safety of ferries are expected to increase thanks to the expansion of sea traffic, the expansion of the offshore fishing industry, and wind farms. It is argued that a single accident by ferry transportation can cause mass mortalities and property loss since the ferry typically carries a lot of people and freight on board [7]. In the relevant research, most studies only focused on the identification of the safety factors of ship navigation, e.g., [10,11]. A few articles further evaluated the risk levels of those factors. In practice, the different risk levels of safety factors should have different corresponding strategies so as to improve the efficiency of safety management for ship navigation [12].

To fill the literature gap, this paper aims to assess the risks to navigation safety for ferries. In this study, the risk factors (RFs) affecting ferry navigation safety are first investigated. Since the RFs' assessments are highly professional problems, a fuzzy Analytic Hierarchical Process (AHP) approach is then used to weight those RFs, by which a continuous risk matrix is constructed to rank the RFs' risks. Finally, ferry operators traveling across the Taiwan Strait were empirically examined to validate the application of the proposed risk-matrix model. The rest of the paper is organized as follows: Sections 2 and 3 explain the risk factors in ferry navigation and the research methods used in this study, respectively. Section 4 discusses the research results. Finally, we provide some conclusions, limitations, and suggestions for further research.

2. Literature Review

2.1. An Overview of Ferry Transportation in Taiwan

Recent years have seen an increase in cross-Taiwan Strait communications. Travel between Mainland China and Taiwan has increased at an 8 percent average annual growth rate between 2010 and 2018 [13]. As shown in Figure 1, currently there are four major ferry routes: (1) Tapie-Pingtan managed by the Lina Wheel (LW), (2) Keelung-Matsus/Dongyin served by Taiwan Horse Star (THS), (3) Kaohsiung-Penghu operated by Tai-hua Wheel (THW), and (4) Taichung-Pingtan operated by the Strait (ST). The specifications of each ferry are also exhibited in Table 1. In addition, there are a few minor ferry routes between Hualien and Suao, including Taitung port, Orchid Island, and Green Island.

Figure 1. Ferry routes between Taiwan and archipelagic islands.

Table 1. The ship profiles of main ferries in Taiwan.

Ferry / Ship Profile				
Ship's name	Tai-Hua Wheel (THW)	Taiwan Horse Star (THS)	Lina Wheel (LW)	Strait (ST)
Build year	1989	2015	2007	2006
Weight (tons)	8134	4958	10,712	6556
Length (m)	120.00	104.60	112.60	97.22
Width (m)	19.30	16.00	30.50	26.60
Speed (knots)	22	21	40	38
Passengers	1150	580	800	750
Crew	21	19	22	22
Operating route	Kaohsiung-Penghu	Keelung-Matsu	Taipei-Pingtan	Taichung-Pingtan
Operated by	Taiwan Navigation Company	Taima Star company	Lina Travel agency	Strait Express

2.2. The Risk Factors of Navigation Safety

According to the European Union's 2008 Safety Research Plan: Safer EURORO Report [14], the RFs for ferry safety were classified into four dimensions, including humanware, hardware, software, and environment [14]. Based on this framework, numerous navigation-related studies have been conducted. Organizational factors, environmental conditions, human mistakes in safety management, and other possible RFs for marine transportation have been identified in recent research [15–17]. People are often injured or killed, and the environment is often polluted as a result of these RFs. As a result, maritime operators and academics have paid particular attention to how to deal with these RFs in order to ensure maritime navigation safety [18].

Accordingly, we depend on previous research and IMO criteria for maritime navigation safety in this work. Based on Safer EURORO's framework [14], this research focuses on the following four key safety evaluation factors for ferry transport: crew factor, ship hardware, ship management, and company management.

2.2.1. Crew Factor (CF)

Relevant studies have indicated that human error is the primary cause of marine accidents, including personal knowledge, skills, talents, attitude, working drive, and awareness [19]. For example, human error was shown to be the root cause of more than 80% of shipping-related incidents [20]. Human error was to blame for 79% of European maritime disasters between 1981 and 1992 [21]. As a result, human error is responsible for over 79 percent of towing vessel groundings [22], almost 26 percent of fire and explosion incidents [23], and approximately 30 percent of onboard fires/explosions. There are internal and external components to the errors in terms of the crew members that could be differentiated. Internal human error can be attributable to work stress, knowledge, self-discipline, or crews' perceived fatalism [24,25]. Conversely, external human error could be caused by the working environment (i.e., unclean workplace, noise, or pilotage-related deficiencies [18] or a harsh natural environment [16], which makes crew members lack foresight and concentration in their duties. Likewise, other onboard mistakes by crew members that could affect maritime operational safety include misjudgment and misunderstanding [21], inadequate technical knowledge [16], a lack of knowledge about the ship system [3], fatigue, poor rescue communication [16,21], or a lack of awareness of survival procedures [10]. It is argued that a crew member's ability to respond professionally to shipping accidents is able to restrict a mass loss of property and life [11]. To sum up, passenger ferry safety assessments must take into account the importance of the crew factor.

2.2.2. Ship Hardware (SH)

One of the most important variables in marine navigation safety is the condition of a ship's mechanical equipment. Related studies indicated that ship accidents caused by mechanical failure range from 10% to 51% of total accidents [8]. In addition, ship structure is shown to be a critical factor in marine transportation's overall safety. The general engineering and technical system, strength and stability, power and propulsion, and maneuverability are the four pillars of shipbuilding excellence [11]. Furthermore, studies have shown the importance of onboard equipment, such as excellent radio communication, nautical lights and searchlights, and the radar system [16], in ensuring ship navigational safety. Vessel operators should pay more attention to some ship equipment failures to reduce the potential risks, such as broken mooring lines, rusted bolts, damaged gas detectors, and crippled exhaust fans [19]. Additionally, other onboard rescue equipment, such as lifeboats, lifejackets, fire extinguishers, and seat belts [8,10,15,18], and communications systems, such as the Automatic Identification System (AIS), Very High Frequency (VHF) radios, and even the Ship Security Alert System (SSAS) for security, have also been demonstrated to be an indispensable part of marine navigational safety practices.

2.2.3. Ship Management (SM)

Ship management is an essential part of maintaining and operating boats in a safe and efficient manner, as well as for minimizing the risk of accidents and mishaps. Since 1998, the maritime sector has used the International Safety Management (ISM) code to standardize ship management. This code mandates that ship operators follow standard operating procedures (SOPs) in order to optimize operational efficiency and minimize risk. In addition to crews' abilities and expertise, the process of managing crew members onboard is widely considered to be an important aspect of increasing ship safety operations, such as crew working hours, workloads, and job allocations [26].

Furthermore, organizing regular exercise and periodic training programs are manifested to be a crucial part of marine risk-prevention strategies for major shipping lines such as COSCO and Yang Ming. On top of that, working on vessels requires a "team effort"; in other words, a "one-man-show" cannot operate the whole vessel effectively and efficiently. It is evident that good interpersonal relationships among seafarers, which enable them to coordinate and cooperate in the workplace, are important for performing operations smoothly and safely on board. Comprehensive maritime accident analyses also found that the lack of team training and poor communication between crews and third parties are prone to major accidents [18].

2.2.4. Company Management (CM)

The process of company management is an important aspect that is crucial to optimizing ferry navigation and improving ferry operators' business performances. For the role of company management in ferry navigation safety, the responsibilities delegated to an executive cover two categories: technical management and crew management. Arguably, technical management services, such as arranging and supervising dry dockings, repairs, alterations, and maintenance, ensure that the vessel's machinery maintains a particular standard of operation and safety. In recent years, crew management has received more attention as an imperative facet of estimating the risks of maritime transportation. In practice, crew management for shipping companies mainly includes the development of safety procedures [3], crew manpower planning [26], and safety training systems [11]. On top of this, regulatory actions [19]; certification counterfeiting; poor inspection [18], incentive and punishment mechanisms [26]; and crew recruitment processes [3] are also a few of the numerous factors that affect ship navigation safety.

2.3. Risk Matrix

To improve maritime safety, the International Maritime Organization (IMO) proposed the Formal Safety Assessment (FSA) procedures to assess safety risks [27]. The process, shown in Figure 2, includes five steps: (1) hazard identification, (2) risk analysis, (3) risk control options, (4) cost-benefit assessment, and (5) recommendations on decisions [28]. In this article, the hazard is defined as any accident that endangers the navigation safety of a ferry. Since the FSA procedure includes complete and concrete implementation steps, it was widely applied in many workplaces of safety management, including maritime transportations [25,26,29], container terminals [28], airfreight transportations [12], etc.

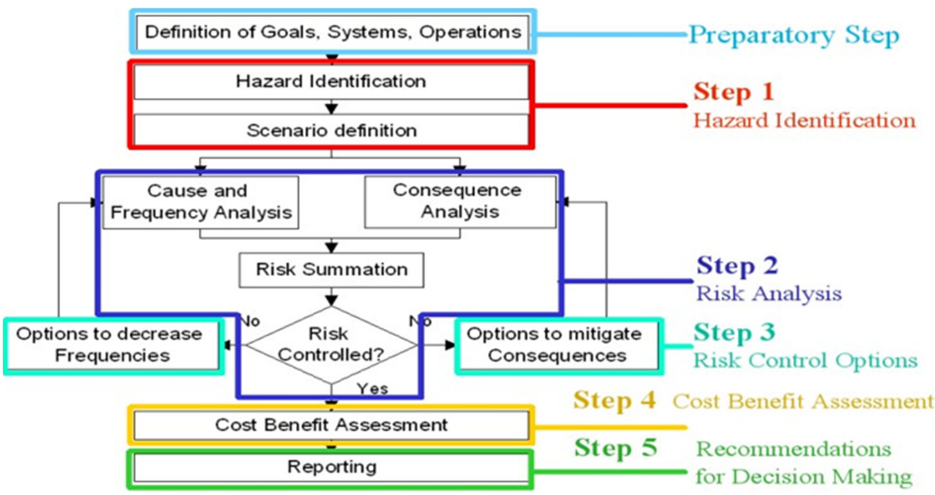

Figure 2. The Formal Safety Assessment (FSA) procedures.

In the FSA procedures, the hazard identification in Step 1 is to define the risk factors (RFs), and a risk matrix is usually employed to analyze the RFs in Step 2 (i.e., Risk Analysis). Traditionally, the risk matrix is constructed based on the consequence and likelihood of the RF (Duijm, 2015). The consequence refers to the extent of loss to an organization when a particular RF is incurred and can be generally divided into 1~4 (or 1~5) levels, such as very serious, major, moderate, minor, etc. The likelihood refers to the number of occurrences of a specific RF within a certain period. Again, it is divided into 1~4 (or 1~5) levels, such as: often occurs, common, less frequently occurs, and rarely occurs.

In the traditional risk matrix, based on the levels of both consequence and likelihood, a two-dimensional panel with a risk value is used to rank the RFs' levels. The panel is divided into several colored areas to characterize the levels. Moreover, a risk value is yielded by the product of the two levels. For example, Figure 3 shows a 4 × 4 risk matrix that ranks the RFs into three levels. The RFs located in the green area with risk values between 1 and 2 are classified as L (low-risk) levels. In contrast, the RFs situated in the yellow and red regions are classified as M (medium-risk) and H (high-risk) levels, respectively. Since the levels of both consequence and likelihood are discontinuous, the risk value is discrete and, as a result, the panel becomes a discrete risk matrix.

Likelihood					
	4	M (4)	M (8)	H (12)	H (16)
	3	M (3)	M (6)	M (9)	H (12)
	2	L (2)	M (4)	M (6)	M (8)
	1	L (1)	L (2)	M (3)	M (4)
		1	**2**	**3**	**4**
		Consequence			

Figure 3. The traditional risk matrix.

In practice, the discontinuity of a risk matrix may limit its applicability with respect to accuracies due to the consistency of the measurement data, risk-matrix grading [28], etc. To improve the shortcomings of discontinuity, the concept of a continuous risk matrix was thus proposed as shown in the curve in Figure 4 [12].

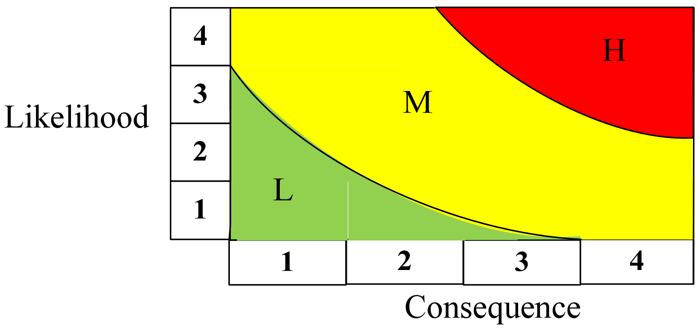

Figure 4. The continuous risk matrix.

3. Research Method

In this paper, the risk factors (RFs) for accidents endangering the navigation safety of a ferry are initially identified. A fuzzy AHP (Analytic Hierarchy Process) is then used to assess those RFs' weights, including both consequence and likelihood. Based on those weights, a continuous risk matrix is developed to assess the RFs' risk levels. Furthermore, the ferries traveling across the Taiwan Strait were empirically investigated, following which, practical management policies for ferry navigation safety are suggested.

3.1. The Risk Factors (RFs)

A total of sixteen RFs are generated based on the ferry's navigational characteristics and literature review in Section 2.2. Each RF is based on one of four factors: crew factor, ship hardware, ship management, and company management.

(1) Crew factor (CF)

In this paper, the CF is defined as the crew's personal perspectives and attitudes regarding ferry safety practices, including safety knowledge, ability to manage shipping, personal self-discipline for work, fatalism cognition, etc. [10,11,16,18,19,21,24–27].

(2) Ship hardware (SH)

In this paper, the SH is defined as the equipment and facilities onboard a ship, including the usability of fundamental navigation equipment for ferry navigation, as well as the availability of emergency rescue systems, safety monitoring systems, and emergency alert navigational aids [3,8,10,11,15,16,18,19,27].

(3) Ship management (SM)

In this paper, the SM is defined as the management of crew operations in navigation, including compliance with standard operating procedures (SOPs), safety drillings, and crew coordination and collaboration. Furthermore, it also includes the development and implementation of different safety management processes onboard [14,16,18,27].

(4) Company Management (CM)

In this paper, the CM is defined as the safety management systems of a shipping company, including the process of crew recruiting, the crew assessment system, technical management, the mechanisms for rewarding and punishing employees, etc. [3,10,11,18,19,26].

Based on the above definitions, a two-layer structure of RFs was created hierarchically. To improve the practical validity of the RFs, three experienced crews working onboard ferries in Taiwan were invited to revise them. Furthermore, they were also asked to check the interdependencies among the RFs. After two rounds of revisions, the final hierarchical structure of the RFs, as shown in Table 2, contained 4 constructs of RFs for the first layer and 16 for the second layer.

Table 2. The risk factors (RFs) for ferry navigation safety.

Layer1: Construct	Layer 2: Risk Factors (RFs)	
Crew Factor (CF)	CF1	Emergency responses: crews' responsive abilities to an unexpected or dangerous occurrence, such as fire, injury, etc.
	CF2	Handling skills: crews' skills in shipping handling, such as gear operations, cargo handling, etc.
	CF3	Personal self-discipline: crews' self-discipline for work, such as work ethics, good health, etc.
	CF4	Fatalistic cognition: crews believe that accidents are destined by God, thereby ignoring safety regulations.
Ship Hardware (SH)	SH1	Navigation equipment: the usability of core navigation equipment for ferry navigation, such as geographic information services, radars, etc.
	SH2	Rescue equipment: the usability of emergency rescue equipment, such as fire extinguishers, lifeboats, medical equipment, etc.
	SH3	Monitoring system: the usability of the safety monitoring system, such as emergency alarms, fire detection, etc.
	SH4	Communications systems: the usability of communications equipment to call for help from shore, such as AIS, VHF, SSAS, etc.
Ship Management (SM)	SM1	Management system: the process of managing crews onboard, such as working hours, task distribution, etc.
	SM2	Safety drillings: the regular exercise of safety drillings onboard.
	SM3	Implementing SOPs: crews' compliance with the standard operational procedures for work.
	SM4	Working climate: the coordination and cooperation among seafarers on board.
Company Management (CM)	CM1	Recruitment system: the process to recruit highly qualified crews.
	CM2	Appraisal system: the appraisal system for crews' working performances.
	CM3	Ship inspection: regularly arranging and supervising dry dockings, repairs, alterations, and maintenance.
	CM4	Performance reward: the mechanisms of reward and punishment for crews' working performance.

3.2. The Continuous Risk Matrix

Based on Figure 4, both weights of consequence and likelihood are employed to construct the traditional risk matrix following which, the RF's risk level is ranked.

3.2.1. The Expert Questionnaire and Research Sample

Since this study proposes a fuzzy AHP approach to weight the RFs, a pair-wise comparison questionnaire with a nine-point rating scale was designed to measure the respondents' perceived scores for each RF, including consequence and likelihood. According to the hierarchical structure of the RFs in Table 2, an expert questionnaire with 4 criteria and 16 sub-criteria was created.

In this study, the top four ferry operators in Taiwan (Taiwan ferries case), as shown in the last row of Table 1, were empirically examined to validate the research. Each ferry operator was asked to provide 4-8 senior crews as respondents. Since the survey items are highly professional, all surveyed subjects must have sufficient work experience in navigation safety. Furthermore, to enhance the validity and reliability of the survey, an assistant was assigned to assist each respondent with completing the questionnaire. Finally, we successfully surveyed 22 respondents. Furthermore, since each crew was asked to answer both the perceived consequence and likelihood of the RFs, the total samples number 44. For verifying the consistency of the 44 measures, both consistency index (CI) and consistency ratio (CR) are used to test the consistency of each sample's pairwise comparison matrix:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

and

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

where $\lambda_{\max}$ is the maximum eigenvalue for each matrix, n is the number of criteria in the matrix, and RI represents a randomized index as shown in Table 3 (e.g., Hus, et al., 2016). Theoretically, Saaty suggested that the CR ≤ 0.1 is an acceptable range [12,30].

Table 3. The values of the RI corresponding to a variety of n.

n	3	4	5	6	7	8	9	10	11	12
RI	0.525	0.882	1.115	1.252	1.341	1.404	1.452	1.484	1.513	1.535

In this paper, the software package Expert Choice 11.5 is first used to find the CI for each sample, then, its CR can be obtained by Equation (2). Results showed six samples' CI or CR > 0.1, which meant that they were inconsistent. Therefore, the questionnaire respondents were asked to modify their answers until their scales fitted the consistency tests.

The respondents' profiles are shown in Table 4. Evidently, all respondents have at least 5 years of work experience and possess workplace safety licenses. The experiential qualifications of the respondents can support the reliability of the survey results.

Table 4. Profiles of the respondents.

Features	Range	Frequency	Percentage (%)
Workplace safety License	Yes	22	100.00
	No	0	0.00
Educational level	Master and above	4	18.18
	University	14	63.64
	College	4	18.18
Age (years)	31~40	8	36.36
	41~50	10	45.45
	Over 50	4	18.18

Table 4. *Cont.*

Features	Range	Frequency	Percentage (%)
Work experience (years)	5~10	4	18.18
	10~20	14	63.64
	Over 20	4	18.18
Job title	Captain	3	13.64
	Officers	7	31.82
	Chief Engineer	2	9.09
	Engineers	5	22.73
	Senior crew	5	22.73

3.2.2. The Weights of the RFs

From the sample data in the Taiwan ferries case, we have 44 positive reciprocal matrixes for each pair-wise comparison of the RFs in each layer, including 22 matrixes for consequence measures and 22 matrixes for likelihood measures. To consider the linguistic fuzziness of respondents when answering the survey, the fuzzy AHP approach was proposed to weight both the consequence and likelihood of the RFs [12,28]. For ease of explanation, we take the RFs in the CF construct with consequence measures as an example to detail the process of the fuzzy AHP approach. As shown in Table 2, the RFs in the CF construct include CF1, CF2, CF3, and CF4.

(1) The integration of multi-respondents' opinions.

In this paper, the geometric mean of the measuring scores from multi-respondents is first found. A triangular fuzzy number parameterized by the geometric mean and two extreme values: the minimum and maximum of the measuring scores is then constructed to integrate the multi-respondent's positive reciprocal matrixes into a fuzzy matrix [30].

(2) The integrated fuzzy positive reciprocal matrix

Suppose $\widetilde{A}$ is the integrated fuzzy positive reciprocal matrix with n RFs as:

$$\widetilde{A} = [\widetilde{a}_{ij}]_{n\times n} = \begin{bmatrix} 1 & \widetilde{a}_{12} & \dots & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & 1 & \dots & \widetilde{a}_{2n} \\ \vdots & \vdots & & \vdots \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & \dots & 1 \end{bmatrix} \quad (3)$$

where the element $\widetilde{a}_{ij}$ is a triangular fuzzy number with parameters:

$$\widetilde{a}_{ij} = \begin{cases} [l_{ij}, m_{ij}, u_{ij}]\text{ , if } i > j \\ [1,\ 1,\ 1]\text{, if } i = j \\ [\frac{1}{u_{ji}},\ \frac{1}{m_{ji}}\ ,\ \frac{1}{l_{ji}}]\text{, if } i < j \end{cases}$$

If we have m positive reciprocal matrix from m respondents, then based on step (1), those m matrixes can be aggregated into a fuzzy matrix $\widetilde{A}$ with elements $\widetilde{a}_{ij}$ as:

$$\widetilde{a}_{ij} = [l_{ij}, m_{ij}, u_{ij}] = \left[\min_{1\le k\le m}\left\{a_{ij}^{(k)}\right\}, \left(\prod_{k=1}^{m} a_{ij}^{(k)}\right)^{1/m}, \max_{1\le k\le m}\left\{a_{ij}^{(k)}\right\}\right]$$
$$i = 1,2,\dots,n,\ j = 1,2,\dots,n \text{ and } k = 1,2,\dots,m.$$

For the data of the CF construct example, we had 22 matrixes. Based on Equation (4), those matrixes are integrated into a fuzzy positive reciprocal matrix, termed $\widetilde{A}\prime$, as:

$$\widetilde{A}\prime = \begin{bmatrix} [1.000,\ 1.000,\ 1.000] & [0.500,\ 0.740,\ 1.500] & [0.571,\ 0.862,\ 1.250] & [0.667,\ 1.149,\ 2.000] \\ [0.667,\ 1.351,\ 2.000] & [1.000,\ 1.000,\ 1.000] & [0.800,\ 1.118,\ 1.750] & [1.500,\ 1.589,\ 2.000] \\ [0.800,\ 1.160,\ 1.750] & [0.571,\ 0.894,\ 1.250] & [1.000,\ 1.000,\ 1.000] & [1.250,\ 1.387,\ 1.750] \\ [0.500,\ 0.871,\ 1.500] & [0.500,\ 0.629,\ 0.667] & [0.571,\ 0.721,\ 0.800] & [1.000,\ 1.000,\ 1.000] \end{bmatrix} \quad (4)$$

(3) The integrated crisp positive reciprocal matrix

In this paper, a weighted geometric mean method is used to defuzzify the $\widetilde{A} = [\widetilde{a}_{ij}]_{n\times n}$ into a crisp positive reciprocal matrix $A = [a_{ij}]_{n\times n}$, in which, the fuzzy element $\widetilde{a}_{ij} = [l_{ij}, m_{ij}, u_{ij}]$ in $\widetilde{A}$ is defuzzified [12,30]:

$$a_{ij} = \sqrt[4]{l_{ij} \cdot 2m_{ij} \cdot u_{ij}}, i = 1, 2, \ldots, n, j = 1, 2, \ldots, n \quad (5)$$

Based on Equation (5), the example matrix $\widetilde{A}\prime$ was defuzzified as:

$$A\prime = \begin{bmatrix} 1.000\ 0.801\ 0.854\ 1.152 \\ 1.249\ 1.0001.150\ 1.659 \\ 1.172\ 0.869\ 1.000\ 1.432 \\ 0.868\ 0.603\ 0.698\ 1.000 \end{bmatrix}$$

Note, that it is easy to test that the matrix $A\prime$ still retains the features of a positive reciprocal matrix [30]. Thus, the simplified method: NGMR (Normalization of the Geometric Mean of the Rows) can be used to find the priority weights of the matrix $A\prime$ (Satty, 2003).

(4) The RFs' weights

Theoretically, the weights of the RFs can be determined from the eigenvectors of the matrix $A = [a_{ij}]_{n\times n}$. Let $W = [w_1, w_2, \ldots, w_n]^T$ represents the vector of the RFs' weights. Then the W can be found by the eigenvector and eigenvalue of A as Saaty [31]:

$$\begin{cases} AW = \lambda W \\ \sum_{i=1}^{n} w_i = 1, i = 1, 2, \ldots, n. \end{cases} \quad (6)$$

If A is a positive reciprocal matrix, Saaty (2003) proposed the simplified method NGMR to find the approximated eigenvectors of A. Let $W = [w_1, w_2, \ldots, w_n]^T$ be the eigenvector of A, then it can be found by the normalized geometric means of a_{ij} as:

$$W = \begin{bmatrix} w \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \left(\prod_{j=1}^{n} a_{1j}\right)^{1/n} / \sum_{i}^{n} \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \\ \left(\prod_{j=1}^{n} a_{2j}\right)^{1/n} / \sum_{i}^{n} \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \\ \vdots \\ \left(\prod_{j=1}^{n} a_{nj}\right)^{1/n} / \sum_{i}^{n} \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \end{bmatrix}, i = 1, 2, \ldots, n. j = 1, 2, \ldots, n. \quad (7)$$

Since the matrix $A\prime$ is a positive reciprocal matrix, based on Equation (7), we have:

$$W\prime = \begin{bmatrix} w_1' \\ w_2' \\ w_3' \\ w_4' \end{bmatrix} = \begin{bmatrix} 0.2319 \\ 0.3060 \\ 0.2706 \\ 0.1915 \end{bmatrix}$$

Further, substituting Equation (7) into Equation (6), we have

$$\lambda I = (AW)W^{-1} \quad (8)$$

where $\lambda I \approx (\lambda_1.\lambda_2, \ldots, \lambda_n)$. Finally, the approximated maximum eigenvalue $\lambda_{\max}$ of matrix A can be found by averaging the $(\lambda_1.\lambda_2, \ldots, \lambda_n)$ as:

$$\lambda_{\max} \approx \frac{1}{n} \cdot \sum_{i}^{n} (\lambda_1 + \lambda_2 + \ldots + \lambda_n) \tag{9}$$

For the example matrix $A\prime$, based on Equations (8) and (9), we had:

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} = \left(\begin{bmatrix} 1.000\ 0.801\ 0.854\ 1.152 \\ 1.249\ 1.000\ 1.150\ 1.659 \\ 1.172\ 0.869\ 1.000\ 1.432 \\ 0.868\ 0.603\ 0.698\ 1.000 \end{bmatrix} \cdot \begin{bmatrix} 0.2319 \\ 0.3060 \\ 0.2706 \\ 0.1915 \end{bmatrix} \right) \cdot \begin{bmatrix} 0.2319 \\ 0.3060 \\ 0.2706 \\ 0.1915 \end{bmatrix}^{-1} = \begin{bmatrix} 4.003 \\ 4.002 \\ 4.000 \\ 4.002 \end{bmatrix}$$

$\Rightarrow \lambda_{\max} \approx 4.002$

(5) The consistency test

Based on the $\lambda_{\max}$ (= 4.002) in Equation (9), both the indexes of CI and CR can be obtained from Equations (1) and (2) in Section 3.2.1 to test the consistency of the matrix $A\prime$. The results show: CI = 0.001 and CR = 0.001. Likewise, we tested the consistencies of the RFs in the other constructs in the Taiwan ferries case. The results shown in Table 5 indicate that all the CI and CR values are less than 0.1, implying that all the positive reciprocal matrixes in the Taiwan ferries case are consistent.

Table 5. The consistency tests for the samples in the Taiwan ferries case.

Measurements	Constructs	CI	RI	CR
Consequence	Layer 1	0.002	0.882	0.002
	Layer 2: CF	**0.001**	0.882	**0.001**
	Layer 2: SH	0.006	0.882	0.007
	Layer 2: SM	0.010	0.882	0.011
	Layer 2: CM	0.010	0.882	0.011
Likelihood	Layer 1	0.003	0.882	0.003
	Layer 2: CF	0.001	0.882	0.001
	Layer 2: SH	0.001	0.882	0.001
	Layer 2: SM	0.002	0.882	0.002
	Layer 2: CM	0.009	0.882	0.010

Note: Boldfaced values represent the CI and CR for the example of the CF construct.

(6) The global weights of the RFs

Based on Equation (7), the local weights of the RFs can be found. Then, the global weights of the RFs can be obtained by multiplying the RFs' local weights by their corresponding constructs' global weights. As a result, in the Taiwan ferries case, the results of the RFs' global weights for consequence and likelihood are shown in the last column of Tables 6 and 7, respectively.

Table 6. The consequence weights of risk factors (RFs).

Layer 1 RFs	Global Weights of Layer 1 (%)	Layer 2 RFs	Local Weights of Layer 2 (%)	Global Weights of Layer 2 (%)
CF	32.53	CF1	23.19	7.55
		CF2	30.60	9.95
		CF3	27.06	8.80
		CF4	19.15	6.23
SH	19.60	SH1	19.55	3.83
		SH2	25.40	4.98
		SH3	27.92	5.47
		SH4	27.13	5.32

Table 6. *Cont.*

Layer 1 RFs	Global Weights of Layer 1 (%)	Layer 2 RFs	Local Weights of Layer 2 (%)	Global Weights of Layer 2 (%)
SM	28.65	SM1	20.17	5.78
		SM2	25.67	7.35
		SM3	30.73	8.80
		SM4	23.44	6.72
CM	19.22	CM1	32.18	6.18
		CM2	19.61	3.77
		CM3	25.80	4.96
		CM4	22.40	4.31

Note: The boldfaced values represent the RFs with higher weights.

Table 7. The likelihood weights of risk factors (RFs).

Layer 1 RFs	Global Weights of Layer 1 (%)	Layer 2 RFs	Local Weights of Layer 2 (%)	Global Weights of Layer 2 (%)
CF	29.48	CF1	24.35	7.18
		CF2	29.90	8.81
		CF3	28.59	8.43
		CF4	17.15	5.06
SH	25.62	SH1	26.17	6.70
		SH2	25.79	6.61
		SH3	25.13	6.44
		SH4	22.90	5.87
SM	22.55	SM1	22.30	5.03
		SM2	23.87	5.38
		SM3	30.66	6.91
		SM4	23.17	5.22
CM	22.35	CM1	28.00	6.26
		CM2	20.53	4.59
		CM3	24.30	5.43
		CM4	27.19	6.08

Note: The boldfaced numbers represent the RFs with higher weights.

Table 6 indicates that for the RFs' consequence weights, CF (32.53%) has the highest weight in the first layer of RFs, followed by SW (28.65%), SH (19.60%), and CM (19.22%). In the second layer, the RFs with higher weights are CF2 (9.95%), CF3 (8.80%), and SM3 (8.80%). Meanwhile, Table 7 shows that in the first layer of RFs, the RF with the highest likelihood weight is CF (29.48%), followed by SH (25.62%), SM (22.55%), and CM (22.35%). In the second layer, the RFs with higher weights are CF2 (8.81%) and CF3 (8.43%).

3.2.3. The Continuous Risk Matrix

In the theory of risk matrix, an RF with a higher consequence weight and higher likelihood weight should be ranked as a higher risk. Based on this conception, a risk value (RV) is thus constructed by the product of the two weights [12,25]. Let C_i and L_i be the consequence and likelihood weights of the *i*th RF, respectively. Then, the RV of the *i*th RF is found as:

$$\mathrm{RV}_i = C_i * L_i,\ i = 1, 2, \ldots, n \tag{10}$$

Finally, the RV can be normalized as:

$$\mathrm{RV}_i = \frac{C_i * L_i}{\sum_{i=1}^{n} (C_i * L_i)} \times 100\%,\ i = 1, 2, \ldots, n \tag{11}$$

Based on Equation (11), and the RFs' weights of consequence and likelihood in Tables 6 and 7, the RVs for each RF can then be found in the fourth field of Table 8, named "RVs". The results show that the RF with the highest risk is CF2 (13.57%), followed by CF3 (11.48%), SM3 (9.42%), and CF1 (8.38%).

Table 8. The results of traditional risk matrix.

Risk Factors	Consequence Weights (%)	Likelihood Weights (%)	RVs (%)	Risk Level
CF2	8.81	9.95	13.57	E
CF3	8.43	8.80	11.48	
SM3	6.91	8.80	9.42	H
CF1	7.18	7.55	8.38	
SM2	5.38	7.35	6.13	M
CM1	6.26	6.18	5.99	
SH3	6.44	5.47	5.45	
SM4	5.22	6.72	5.43	
SH2	6.61	4.98	5.09	
CF4	5.06	6.23	4.87	
SH4	5.87	5.32	4.83	
SM1	5.03	5.78	4.50	L
CM3	5.43	4.96	4.17	
SH1	6.70	3.83	3.98	
CM2	4.59	3.77	2.68	
CM4	6.08	4.31	4.05	

In this paper, a continuous risk matrix with four risk zones is constructed to rank the RFs' risk levels. As shown in Figure 5, the risk matrix consists of an x-axis representing consequence weights and a y-axis depicting likelihood weights. Based on Equation (11), the matrix can be divided into four risk zones by three decreasing curves with different RV means. Firstly, the middle curve with RV = 6.25% is obtained by averaging the RVs of all the RFs in Table 8. The curve is then used to divide all the RFs into two groups by their RVs. Group one contains 4 RFs (CF2, CF3, SM3, and CF1) and group 2 includes the remaining 12 RFs. Averaging the four RVs of the RFs in group one, we have the second curve with the mean RV =10.71%. Similarly, the third curve with TRV = 4.76% can be obtained by averaging the 12 RVs of the RFs in group two.

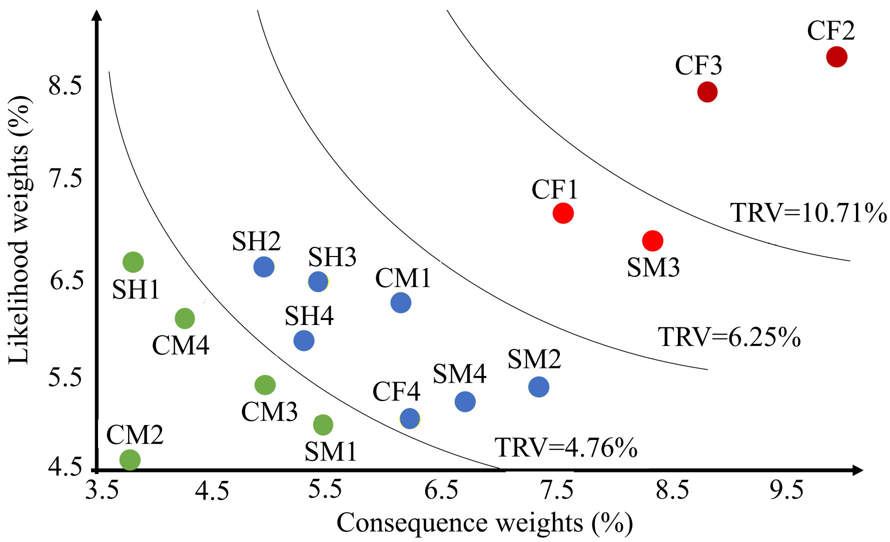

Figure 5. The risk matrix for the Taiwan ferries case.

The results, shown in the last field of Table 8 and visualized in Figure 5, indicate that two RFs (CF2 and CF3), are ranked as E level (extreme-risk), and two RFs (SM3 and CF1) as H (high-risk). Furthermore, seven RFs were classified as M level (medium-risk), and five RFs as L level (low-risk).

4. Discussion

The result of the risk matrix assessment for the Taiwan ferries case shows that four RFs are classified as E level (CF2 and CF3) and H level (SM3 and CF1). Based on these results, we conducted a post-interview with some practical experts among the surveyed respondents and proposed the following management suggestions for ferry operators:

1. CF2 (crews' skills in shipping handling)

Generally, crew members must be qualified ahead of being recruited to work onboard, so their proficiency in ferry passenger handling could be assured. However, in the past decade, navigation technology has progressed rapidly and new navigation safety rules have been updated accordingly. Under these circumstances, crew members need to continuously acquire new knowledge of shipping handling. This paper suggests that ferry companies should connect and cooperate with academic institutions to regularly train crew members in specialized fields of new knowledge, such as the search and rescue of victims in distress at sea, new government regulations on maritime navigational safety, and risk identification and assessment. This suggestion is expected to reduce accidents in the workplace and prompt human safety [28]. Furthermore, the results of training programs should also be used to appraise crew members' annual performances so that maritime personnel are motivated to join training programs in earnest.

2. CF3 (Crews' self-discipline for work)

Maritime transportation has witnessed many accidents in the workplace due to crew members' health [28]. So, personal self-discipline for work should be paid more attention to, as evidenced by our article. Any level of alcohol or illegal drug consumption by crew members threatens the safety of ferry operations, other crew members, as well as passengers. Overworking and burnout, which is an alarming trend among employees in the shipping industry globally, also have adverse effects on ferry navigation safety. To tackle these circumstances, this paper suggests that ferry companies should frequently utilize recorded data to check crew operations on board after each voyage. Any abnormal actions occurring need to be reported immediately to minimize the likelihood of incidents. It is also advised that safety alert devices be installed to prevent captains from becoming overly fatigued as a result of overworking or sleeplessness or to detect the use of illicit drugs and alcohol.

3. SM3 (Compliance with SOPs)

As mentioned earlier, many maritime accidents are attributable to crew or human error. To prevent such accidents, shipping companies should establish standard operational procedures (SOPs) for crew members to follow. Currently, compliance with SOPs is occasionally ignored. In Taiwan, overcrowding and overloading are also major problems causing navigational risks for ferry transport, which could result in crew members neglecting the company's SOPs. This paper suggests that overcrowding and overloading should be inspected carefully before commencing a voyage; that ferry owners should be heavily fined for overloading; and that carrying commercial cargo in passenger ferries should be strictly prohibited [9]. Furthermore, in practice, because safety regulations often change over time, this paper also suggests that ferry managers should update existing SOPs regularly and ask crew members to implement SOPs accurately in navigation operations to reduce accidents.

4. CF1 (Emergency responses)

In practice, a crew's emergency response capabilities can be strengthened by sufficient safety knowledge and training. Based on the post-interviews, this study recommends the following for this RF:

(1) Carry out regular drills to enhance the crew's emergency response capabilities, such as the use of rescue equipment, conducting emergency evacuations, and general response procedures.
(2) Ask crews to take functional recurrent training, through practical operations or online learning systems (E-Learning), to regularly renew their qualification licenses.
(3) Encourage and subsidize crews to participate in seminars at academic institutions to enhance their safety knowledge, such as accident features, identifications, preventions, rescues, etc.

5. Conclusions

In practice, ferries are the preferred form of transport for cargo and passengers between islands with relatively short distances. However, some operational safety standards in ferry transportation are easily ignored, thus they are prone to dangerous accidents. Therefore, ensuring ferry navigational safety has attracted much attention from academics, policymakers, and practitioners. The purpose of this paper was aimed at assessing the risks to navigation safety for ferries. In the article, sixteen risk factors (RFs) were first investigated for ferry navigation. A continuous risk matrix based on a fuzzy AHP approach was then developed to evaluate the RFs' risks. The risk assessment approach may provide references for related research in the safety management of short-distance passenger ships, including ferries and cruise ships.

To validate the practical application of the research, the main ferry operators in Taiwan were empirically investigated. The results identified four top-layer RFs including crews' skills in shipping handling, personal self-discipline for work, compliance with SOPs, and emergency responses. With regard to the results, some management policy improvements are suggested. These results provide helpful information for TNC to improve its navigational safety. Furthermore, the empirical results are representative and may also provide practical management references for foreign ferry companies.

Although this paper succeeds in assessing navigation safety for ferries, several potential limitations can be noted for further studies. First, this article uses fuzzy AHP to evaluate the weights of the RFs. One of the basic assumptions of AHP is that the criteria (i.e., RFs) must be independent of each other. However, the independence among the RFs in this study was just verified by practical experts. In the questionnaire design stage, they were interviewed to revise the RFs and the hierarchical structure based on their subjective judgments. Therefore, in theory, it may not be rigorous enough. Future research could consider adopting ANP (Analytic Network Process) or the AHP revision model to assess the RFs [30]. Secondly, this study investigated the ferry navigational safety in the Taiwan Strait as an empirical study. However, different ferry routes may differ in their environmental features. Thus, this paper's results may not be completely applicable to ferries in other areas. Lastly, in this study, 22 experts from Taiwanese ferries were empirically surveyed. This article also adopted an interview survey instead of a mailed survey to improve the validation of the survey. Therefore, the validity and reliability of the research results could be verified. However, to better confirm the empirical results, more representative samples may be needed in future research.

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Strategic Crisis Response of Shipping Industry in the Post COVID-19 Era: A Case of the Top 10 Shipping Lines

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Abstract: Shipping has played a pivotal role during the epidemic, ensuring that the global logistics functions without disruption. COVID-19 hit various industries around the world, and shipping was no exception. How the shipping industry responds to the crisis and simultaneously shoulders its respective responsibility in the world's battling the crisis is thus worth exploring in depth. This study takes the top 10 global container shipping capacity liners, which account for 84.7% of the worldwide capacity, as research objects. A corpus for text analysis was constructed collecting press releases and advisories issued on official websites of these 10 container shipping companies from January 2020 to July 2021. Comparison studies were made horizontally among ten shipping companies and longitudinally for crisis evolution patterns into three sub-corpora of Pre/early-Crisis, Crisis-in-Progression, and Post-COVID-19-Era. Quantitative findings were explored and elaborated further under a comprehensive theoretical framework integrating crisis management and communication, corporate social responsibility (CSR), and maritime management (MM). The extracted positive and negative keywords revealed textual characteristics and emergency response strategies on the part of shipping lines in the Pre/early-Crisis, Crisis-in-Progression, and Post-COVID-19-Era. The inclusion of the themes of pursuing sustainability in the shipping lines' responses to such worldwide crisis as COVID-19 is out of the common knowledge of crisis management but reveals the commitment and strategies on the part of the industry. The findings provide a reasonably comprehensive picture of the efforts made by large container shipping companies to respond to COVID-19 and the measures taken to soothe stakeholders. This paper extends and relearns crisis management, CSR, and MM theories through integrating the fulfilling of cooperate social responsibilities in maritime management as the cooperate crisis responses, thus proposing the integrity of the three topics. Moreover, management recommendations are provided for shipping company management, IMO, and port authorities.

Keywords: crisis response; corporate social responsibility; container shipping; text analysis; COVID-19

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1. Introduction

The shipping industry is an essential link in the global transportation of goods and is at the heart of the logistics supply chain, transporting more than 80% of the world's goods [1]. However, the sudden outbreak of COVID-19 has brought uncertainty into the shipping industry and has had severe repercussions such as reduced pilotage safety [2], cruise ship suspensions [3], ports closure [4] and crew change crisis [5]. UNCTAD estimated that the shipping trade contracted by 3.8% in the first half of 2020. However, maritime trade grew by 4.3% [6]. The shipping industry also showed some resilience in responding to the crisis caused by the epidemic, with no significant disruptions to the logistics supply chain.

Ships transport goods to every part of the world, especially to secure the transportation of essential goods such as sanitary equipment, electronic components, food, and fruits during epidemics. Ships' routes have woven international shipping into a network and simultaneously connected every stakeholder [7]. Compared with other shipping markets, container shipping lines are more closely linked to supply chain customers and are an integral part of the global supply chain. Furthermore, large logistics service providers, international retailers, and globally distributed production networks embed in the liner service. Shipping carriers set quality, speed, reliability, flexibility, and cost as their performance goals to improve competition [8]. Container shipping companies also take on social media engagements [9]. Maritime transportation is primarily a B2B industry and is recognized as the backbone of international trade [10]. Container shipping is essential to maritime transportation because it transports semi-manufactured and manufactured goods closely related to people's daily lives. Therefore, the container shipping industry must disclose its sustainability conditions precisely and correctly [11]. Meanwhile, shipping companies regularly release news and advisories on their websites to highlight their strengths in the shipping market and thus attract the attention of stakeholders. Press releases are easily accessible to the public and are a vital tool for leaders to communicate company performance and company measures [12]. The importance of press releases as part of a company's disclosure strategy has been widely acknowledged [13–15]. Alphaliner's statistics show that the top 10 container shipping companies account for approximately 84.7% of the global container capacity (see Table 1) [16]. Due to this particular market structure, the CSR activities of the top carriers can easily influence the industry in general and can be emulated by smaller shipping companies [17].

Table 1. Top 10 shipping lines (market share and total operated TEU capacity) as per.

Rank	Operator	Market Share (%)	TEU
1	Maersk	16.90%	4249659
2	Mediterranean Shg Co	16.90%	4238730
3	CMA CGM Group	12.50%	3146843
4	COSCO Group	11.70%	2944673
5	Hapag-Lloyd	7.00%	1758188
6	ONE (Ocean Network Express)	6.30%	1572329
7	Evergreen Line	5.80%	1449424
8	HMM Co Ltd.	3.30%	823408
9	Yang Ming Marine Transport	2.60%	662047
10	Wan Hai Lines	1.70%	423429
	Total	84.70%	21268730

Source: Alphaliner (https://alphaliner.axsmarine.com/PublicTop100/ (accessed on 3 December 2021)).

This pandemic has highlighted the advantages of container shipping and the significance of cooperation between shipping companies. Some studies have been carried out on CSR in shipping logistics [18,19], the competitiveness of container ports [20], container sustainability [21], service characteristics of container liner shipping [22,23], as well as environment pollution [24]. During the epidemic, Xu, et al. [25] employed a dynamic panel data model to analyze the trade data of the European Union, North America, and Southeast Asia released by the National Bureau of Statistics and found that government control measures had a negative impact on export trade. In contrast, import trade increased accordingly. Verschuur, et al. [26] investigated the impact of the epidemic on global trade based on Automatic Identification System (AIS) data. Notteboom, et al. [27] compared the epidemic and the financial crisis to study the demand shocks to containers and ports. From a logistics triad perspective, Russell, et al. [28] investigated four dimensions of port logistics capacity: seaside interface, platform, landside interface, and system-wide [28]. However, few scholars have examined the shipping industry's crisis response strategies in light of CSR, and MM through text mining of industry discourses.

Shipping companies have disclosed their corporate strategies and emergency management measures during the epidemic, leaving three critical issues worthy of in-depth examination: (1) What measures have the companies taken to respond to this crisis? (2) Are the press releases and advisories issued by the companies in line with CSR? (3) What lessons and implications can we learn from the dynamic crisis responses of the industry?

To address these 3 research questions, a large-scale corpus was built comprised of press releases and advisories from January 2020 to July 2021 on the websites of the top 10 shipping companies worldwide. This paper integrates the theories of crisis management and communication, CSR, MM in the exploration of quantitative results from a computerized semi-automated analysis of textual features in corpus. Through text mining, the crisis strategies adopted by shipping companies in different stages including stakeholder communication and the company's sustainability commitment are explored. Therefore, this study contributes to the sustainable development of the shipping industry post-epidemic, both from academic research and practitioners' practice.

2. Theoretical Framework

2.1. Crisis Management and Communication

A crisis can be defined as "an unpredictable event that threatens important expectancies of stakeholders related to health, safety, environmental, and economic issues, which can seriously impact an organization's performance and generate negative comments" [29]. Many scholars have studied crisis management given crises' sudden, uncertain, and hazardous nature. The scope of crisis management includes crisis prevention, crisis preparation, crisis response, and crisis correction [30]. There are 2 research paradigms in crisis management: (1) a static perspective that examines the crisis as an event and focuses on the results caused by the crisis, and (2) a dynamic perspective that conceptualizes the crisis as a process. In this situation, a "crisis was perceived as a long incubation process that suddenly manifests itself under the influence of a 'precipitating' event" [31]. According to Zhang and Sun [32], the crisis caused by the epidemic in the shipping industry can be viewed as a process. This study adopts the crisis-as-process perspective to examine the crisis response of shipping firms pre-, during and post-epidemic crisis. In this view, crisis management is considered as "managing attention to 'weak signals' of crises-in process, in-event organizing, and post-event actions to protect a system and (when necessary) bring it back into alignment" [33].

Based on a process perspective, two essential attributes affect the effectiveness of crisis management. Firstly, in light of different stages of a crisis, the impact on the organizational system is analyzed, and thereby adversity responses of the organization are carried out. This can help the business have a clear understanding of the complexity of crisis management [34]. Secondly, crises can influence stakeholders at different levels, so the organization must continuously adapt its business model and mode to allow the organization to gain resilience and strengthen its crisis response capabilities [33].

Corporate communication can be effective in helping companies with crisis management [35]. Communication plays an essential role in instilling confidence and gaining trust from stakeholders by developing strategic initiatives to enhance the company's reputation. Therefore, companies can communicate corporately through the media and other communication modes (for example, press releases), which are strategic ways to enhance corporate image building.

2.2. Corporate Social Responsibility (CSR)

Pawlik, Gaffron and Drewes [18] firstly presented a definition of CSR for the container shipping industry: "the integration of social and environmental concerns in the business operations of shipping firms and the interaction with stakeholders voluntarily" [18]. The main issues related to CSR in the shipping sector are the safety, welfare, and health of seafarers, human rights, ethical considerations, and stakeholder participation, focusing on marine environmental protection [36]. Most shipping companies have practiced CSR and integrated it into their business at a strategic and visionary level [37,38]. CSR in the shipping framework includes four key impact areas: CSR governance, social responsibility, environmental responsibility, and ocean responsibility [39]. The shipping industry primarily commits to the Sustainable Development Goals (SDGs) by promoting sustainable economic, environmental, and social development [40]. However, in recent years, shipping companies have focused on environmental protection, such as the sulfur content cap implemented by the International Maritime Organization in 2020, limiting the sulfur content of fuel oil to 0.5% (by mass) [41]. In addition, during this crisis, crew members are on the front lines of the logistics supply chain, and their health is a significant concern [5]. In other words, the issues mentioned above are the focus of CSR, and they are also the contents that need to be analyzed in-depth in this study.

2.3. Maritime Management (MM)

MM involves utilizing and manipulating human, financial, technical, and natural resources related to the sea, maritime navigation, shipping, port development, and coastal protection. MM promotes economic growth, price stability, cargo and passenger transport, and the commercial activities of shipping organizations [42]. Strategic maritime management deals with the major intended and emergent initiatives taken by general managers on behalf of both ship owners and other stakeholders, involving the utilization of resources, to enhance the performance of maritime organizations in the global marine environment [43]. The shipping industry is a vast network system, which involves stakeholders such as IMO, shipping companies, ship owners, crew members, ship agents, consignees, etc. [44]. Maritime management ensures the orderly operation of the shipping industry and plays a vital role in the healthy development of the shipping industry [45]. During the epidemic, IMO, as the organization manager of the shipping industry, has called on member states and international organizations to take MM measures in the form of maritime proposals to reduce the epidemic's impact [32]. Shipping companies have been publishing on their official websites company news and, in particular, measures taken to preserve their image, protect their employees' interests, and attract investors' attention. In addition, sustainability in shipping is one of the most critical issues, and shipping companies have integrated social and environmental issues into their business operations and interactions with stakeholders [46].

Due to the international nature of the shipping industry, the impact of the crisis on shipping stakeholders is also global. The shipping lines communicate with the outside world through press releases, showing that they are actively fulfilling CSR. In other words, they are performing crisis management and MM to guarantee sustainability. Therefore, this study integrates a theoretical research framework, as shown in Figure 1, to lay the foundation for subsequent analysis of the data.

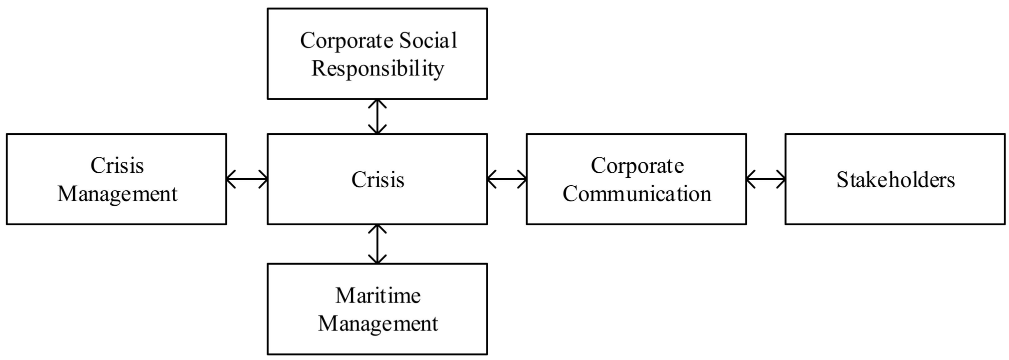

Figure 1. Integrated theoretical framework.

3. Methodology

The study collected the press releases and advisories list on these companies' websites from January 2020 to July 2021. It should be noted here that COVID-19 began to emerge in January 2020 and has continued to impact the shipping industry as time has progressed. In addition, in 2018, COSCO Shipping acquired OOCL, so COSCO Group news includes those of COSCO shipping line and OOCL. To compare the news of ten shipping companies horizontally, this research establishes ten sub-corpora, as shown in Table 2. In Section 4.1, the word cloud analysis can analyze the lexical features of corporate discourse at a macro level, drawing similarities and differences.

Table 2. The specific descriptions of the ten corpora.

Operator	Files	Tokens	Types	Lemmas
Maersk	213	139,980	10,071	8867
Mediterranean Shg Co	91	34,108	4576	4091
CMA CGM Group	107	61,096	6315	5487
COSCO Group	131	39,615	4683	4055
Hapag-Lloyd	42	25,569	2804	2255
ONE (Ocean Network Express)	182	48,533	4697	4172
Evergreen Line	23	10,440	2138	1890
HMM Co Ltd.	18	6338	1689	1560
Yang Ming Marine Transport	92	25,375	3274	2830
Wan Hai Lines	27	4652	927	858
Total	926	395,596	19,716	17,143

Source: Top 10 container shipping companies.

Simultaneously, based on the crisis process view, this study de-constructed the corpus into three sub-corpora in chronological order. Stage 1 ran from January 2020 to February 2020 at the beginning of the crisis, the dawn phase. In March 2021, the vaccine was developed and IMO called on member states to prioritize vaccination of seafarers. For this reason, March 2020 to February 2021 is considered as the crisis in progress, during which the crisis peaked. We thus established March 2020 to February 2021 as Stage 2. After March 2021, when the world entered the post-epidemic era and the shipping industry entered the late stage of the crisis, we set up March 2021 to July 2021 as Stage 3. The specific information of the three corpora is shown in Table 3.

Table 3. The specific descriptions of the three corpora.

Phase	Files	Tokens	Types	Lemmas
Stage 1	82	32,689	5062	4510
Stage 2	498	199,896	13,630	11,610
Stage 3	346	162,576	11,767	10,304
Total	926	395,161	19,716	17,143

In recent years, text analysis has proven to be a practical paradigm for qualitative and quantitative scientific research. One or more methods can be applied to draw statistical inferences from the textual aggregate [47,48]. Several scholars have used text analysis methods for interdisciplinary research, such as management [49], shipping CSR [32], sociology [50], and engineering [40], suggesting that text analysis has a wide range of application scenarios. This study employs word clouds for qualitative analysis and corpus linguistics for quantitative research, which complement each other. Word cloud has become a straightforward and visually attractive text visualization method. The word cloud generated for the text body can be used as a starting point for in-depth analysis [51]. For example, they help determine whether a given text is relevant to a specific information need. Word cloud, as one of the methods of text analysis, has been applied in patent analysis [52], opinion mining [53], risk assessment [54], maritime accident analysis [55]. However, word cloud only provides isolated word statistics without considering words' linguistic aspects and relations. Corpus linguistics exactly compensates for the drawbacks of word clouds by allowing a greater focus on specific words and the relationships between words. Corpus linguistics is perhaps best described for the moment in simple terms as the study of language based on examples of "real life" language use [56]. The corpus referred to "a collection of texts (a 'body' of language) stored in an electronic database" [57]

The research objects of this paper are news and announcements, which are naturally occurring language uses and fit right into the corpus. Keywords and concordance analyses are two core and practical research methods in corpus linguistics. A keyword is a word that "appear(ed) in corpus statistically significantly and more frequently than expected by chance compared to a larger or equal-sized corpus" [57]. In other words, keyword analysis identifies words that are statistically more frequent in a particular corpus or text when compared against another corpus [58]. After extracting keywords, a more in-depth study is carried out through concordance analysis, which identifies critical textual themes. Concordance analysis of keywords in context reflects that the immediate context of keywords could be explored through the set of consistency lines of keywords, and the pattern of each focus word can be observed [59]. Keyword analysis and concordance analysis are conducted through LancsBox software, equipped with a powerful corpus processing function [60,61]. It is essential to emphasize that the three stages have different corpus sizes, and the authors have applied relative frequencies to the corpus for standardization with a 99.99% confidence ($p < 0.001$). The keywords are obtained by comparing two corpora based on maximum likelihood estimation, one of which is the reference corpus. The keywords in this paper are divided into positive keywords, which belong to the reference corpus, and negative keywords, which belong to the other. The keywords are obtained by comparing two corpora based on the Log-Likelihood significance test. In addition, stop words and company names are removed from further analysis to focus on lexical patterns and reduce bias in the sampled data.

4. Results

4.1. Word Cloud Analysis

A "word cloud" is a visual portrayal of word frequency in the composed text. The more often the word is contained within the article being analyzed, the larger it appears in the created image. Infrequent and grammatical terms are removed so that the resulting pictorial representation illustrates the most common words of significance. Figures 2 and 3 visualize the word cloud of the ten companies. "*customer*", "*customers*", "*service*", and "*services*" appear in the word cloud of each company, illustrating the customer-first and service-first philosophy of shipping liners. "*Global*" and "*world*" reflect the global trade attributes of the shipping industry. "*Port*", "*ports*", the names of ports (for example, "*Ningbo*", "*Yantian*", "*Qingdao*", "*Pusan*", "*Kaohsiung*", "*Taibei*", "*Shanghai*") and Suez Canal, on the one hand, underline the importance of shipping infrastructure development. On the other hand, they respond to the timely dissemination of port and canal information to provide quality services to cargo owners, freight forwarders, and other stakeholders. "*Technology*", "*digital*", "*solution*", "*solutions*" all occur in MAERSK and MSC, demonstrating their focus on using digital technology to solve current problems in the logistics supply chain. "*Emissions*", "*carbon*", "*gas*" and "*air*" are more frequently found in MSC and CCG, indicating that they pay more attention to environment protection. "*Time*", "*times*" emerge more frequently in MAERSK, MSC, COSCO, HL, ONE, EVERGREEN, and YMM, embodying that these companies attach great significance to the timeliness of container ships. Therefore, based on the overall and individual analysis, the focus and tendency of corporate communication can be derived.

4.2. Keyword Analysis

Firstly, taking Stage 1 as the reference corpus and comparing Stage 1 with Stage 2, positive and negative keywords can be derived, as shown in Tables 4 and 5. Table 4 reflects the overused words in corporate communication at the beginning of the Stage 1 crisis. "*Novel*" indicated that companies have realized the novel coronavirus, which might affect enterprise operation, for example, "*securities*", "*detention*", "*difficulties*" and "*crises*". "*Reopen*", "*fee*", "*passion*", "*blockchain*", "*training*" and "*alliance*" were the keywords that guaranteed the company's proper functioning. Although shipping companies were aware of the possible impact of the epidemic on their business, companies were still active in shipping cargoes such as "*breakbulk*", "*fruit*", "*vegetable*". This, in turn, indicates that containers play an essential role in the supply of daily necessities. "*Reopened*" was for "*port reopened*", which facilitated the loading and unloading of goods at the port. Table 5 list the overused words in Stage 2 relative to Stage 1. Novel coronavirus was identified as "*COVID-19*", and for the first time in Stage 2, "*pandemic*" appeared at a high frequency and with a relative frequency of 10.31. This shows that in Stage 2, the crisis began to intensify. "*Medical*" and "*vaccine*" revealed the measures taken in response to COVID-19. The crisis significantly impacted the shipping industry, mainly in "*home*", "*lockdown*", "*delays*", "*inventory*". While companies responded to the crisis, they actively focused on key populations, including "*seafarers*" and "*children*". The sustainability of the shipping industry was emphasized through "*sustainability*" and the company's focus on environment protection, such as "*fuels*".

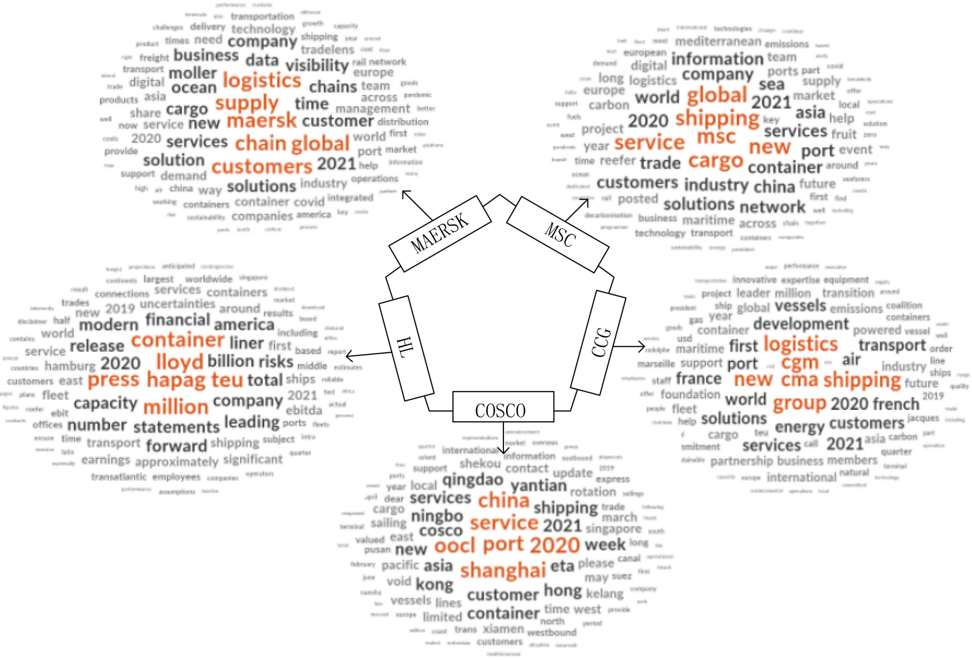

Figure 2. Word cloud of MAERSK, MSC, CCG, COSCO and HL.

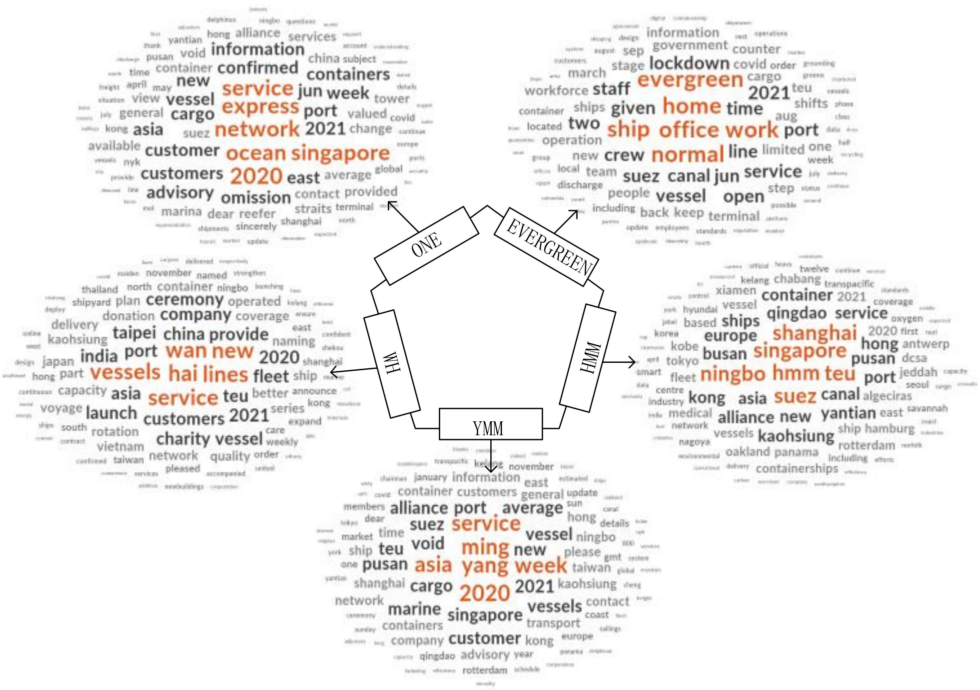

Figure 3. Word cloud of ONE, EVERGREEN, HMM, YMM and WH.

Table 4. Positive keywords for Stage 1 to Stage 2.

Type	Stage 1		Stage 2		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Reopened	18.05	6.33	0.10	17.55	17.32
Fee	4.28	5.32	0.05	22.29	5.03
Securities	4.28	5.26	0.10	22.29	4.80
Breakbulk	3.98	5.87	0.45	15.35	3.43
Passion	2.75	5.26	0.10	15.96	3.41
Novel	3.67	3.58	0.40	10.64	3.34
Fruit	9.79	3.53	2.30	8.63	3.27
Mainland	3.06	5.79	0.25	15.15	3.25
Detention	2.75	5.52	0.20	19.69	3.13
Extension	3.06	5.35	0.30	11.89	3.12
Blockchain	3.37	8.80	0.55	9.05	2.82
Vegetables	3.06	4.75	0.65	10.44	2.46
Training	2.75	6.98	0.55	10.17	2.42
Difficulties	1.53	4.68	0.15	14.75	2.20
Alliance	19.58	3.34	8.50	3.92	2.17
Crises	1.22	9.00	0.05	22.29	2.12

Note: The positive keywords are arranged from large to small by the statistic.

Table 5. Negative keywords for Stage 1 to Stage 2.

Type	Stage 1		Stage 2		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Pandemic	0	0	10.31	2.77	0.09
Home	0.31	9.00	9.40	7.88	0.13
COVID-19	1.53	6.22	14.81	2.76	0.16
Crisis	0	0	3.90	4.79	0.20
Sustainability	0.61	6.63	6.25	5.07	0.22
Inventory	0	0	2.85	5.46	0.26
Medical	0	0	2.50	7.42	0.29
Fashion	0	0	2.50	10.80	0.29
Vaccine	0	0	2.30	13.70	0.30
Origin	0	0	2.15	4.50	0.32
Lockdown	0	0	1.90	7.70	0.34
Seafarers	0	0	1.85	9.24	0.35
Fuels	0	0	1.85	6.66	0.35
Children	0	0	1.80	9.14	0.36
Resilience	0	0	1.45	7.78	0.41
Delays	0	0	1.30	5.50	0.43

Note: The negative keywords are arranged from small to large by the statistic.

Secondly, we took Stage 2 as the reference corpus and compared Stage 2 and Stage 3 in order to obtain positive and negative keywords, as shown in Tables 6 and 7. Table 6 lists the overused words for Stage 2 relative to Stage 3. Compared with Table 5, the words "*blank*", "*health*", "*crew*", "*outbreak*", "*masks*", "*weather*", "*recycling*", "*recovery*", "*eco-friendly*", and "*restructuring*" have been added in Table 6. "*Blank*" is for "*blank sailing*", indicating the impact of the outbreak on shipping lines. "*Fashion*" appears in Tables 5 and 6, which can be analyzed by viewing the specific context through KWIC (keyword in context) in Section 4.3. Besides, Table 6 also pays attention to environmental protection (for example, "*recycling*", "*eco-friendly*"). With the development of the COVID-19 vaccine and the gradual vaccination of crew members, Stage 3 entered the post-epidemic era. The keywords listed in Table 7 highlight the critical elements of Stage 3 corporate communications. The potential impact of COVID-19 on the shipping industry was becoming more and more significant, such as "*insufficient*", "*delays*", "*shortages*", "*patients*", "*congestions*". While responding to the crisis, companies were also actively concerned with environment protection (for example, "*decarbonization*", "*carbon-neutral*", "*fuels*"). "*Women*" and "*truck*" are also of interest, which will be analyzed in the Concordance analysis section.

Table 6. Positive keywords for Stage 2 to Stage 3.

Type	Stage 2		Stage 3		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Alliance	8.50	3.92	0.55	8.54	6.12
Home	9.40	7.88	2.34	6.42	3.12
Blank	1.90	7.56	0	0	2.90
Health	3.95	4.96	1.17	5.34	2.28
Crisis	3.90	4.79	1.17	5.79	2.26
Crew	4.35	5.09	1.60	5.05	2.06
Outbreak	1.45	6.72	0.25	9.90	1.97
Masks	1.10	11.26	0.12	15.63	1.87
Lockdown	1.90	7.70	0.55	7.79	1.87
Weather	2.00	4.43	0.62	6.73	1.86
Recycling	1.15	15.20	0.18	10.88	1.82
Vaccine	2.30	13.70	0.92	13.63	1.72
Recovery	2.40	4.45	1.11	6.18	1.61
Eco-friendly	0.55	8.16	0	0	1.55
Restructuring	0.50	8.73	0	0	1.50
Fashion	2.50	10.80	1.41	8.31	1.45

Note: The positive keywords are arranged from large to small by the statistic.

Table 7. Negative keywords for Stage 2 to Stage 3.

Type	Stage 2		Stage 3		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Insufficient	0.05	22.29	2.46	10.98	0.30
Security	1.05	7.93	4.67	3.63	0.36
Decarbonization	0.75	8.42	3.44	4.55	0.39
Delays	1.30	5.50	4.80	3.17	0.40
Block	0.75	15.48	3.26	6.18	0.41
Women	0.10	15.98	1.35	9.13	0.47
Innovation	2.00	5.13	5.35	3.36	0.47
Blockchain	0.55	9.05	2.03	5.87	0.51
Truck	1.00	6.93	2.89	5.11	0.51
Vaccinations	0	0	0.86	14.36	0.54
Shortages	0.30	11.35	1.35	6.55	0.55
Patients	0	0	0.74	7.47	0.58
Carbon-neutral	0.55	6.98	1.60	7.00	0.60
Fuels	1.85	6.66	3.44	5.03	0.64
Congestions	0.15	17.84	0.84	7.23	0.66
Last-mile	0.10	16.58	0.55	10.27	0.71

Note: The negative keywords are arranged from small to large by the statistic.

Thirdly, two researchers read the relevant concordance of all the keywords listed in Tables 4–7 from the actual data sources (press releases and advisories). The themes appearing in the three corpora were validated by a data triangulation process, in which external sources, such as Maritime Reporter and Engineering News, Marine Technology Report, Marine News, Maritime Logistics Professional, as well as the extant literature [18,32,41,62], were acquired to justify the coding of these themes. Based on triangulation, on the one hand, the thematic coding can be justified, and on the other hand, it helps the researchers to interpret the data. The three corpora then reflected the evolution of the COVID-19 pandemic (see Table 8).

Table 8. Major themes.

Corpora	Themes	Keywords Used
Stage 1	Crisis	Novel, Detention, Extension, Difficulties, Crises
	CSR	Fee, Breakbulk, Passion, Fruit, Mainland, Vegetables
	MM	Reopened, Securities, Blockchain, Training, Alliance
Stage 2	Crisis	Pandemic, Home, COVID-19, Crisis, Medical, Vaccine, Lockdown, Delays, Blank, Health, Outbreak, Masks
	CSR	Sustainability, Inventory, Fashion, Origin, Children, Eco-friendly
	MM	Seafarers, Crew, Fuels, Resilience, Alliance, Weather, Recycling, Recovery, Restructuring
Stage 3	Crisis	Insufficient, Delays, Vaccinations, Shortages, Patients, Congestions
	CSR	Women, Innovation, Truck, Decarbonization, Carbon-neutral
	MM	Security, Blockchain, Block, Fuels, Last-mile

The crisis evolved from "*delays*" and "*detention*" in Stage 1 to "*blank sailing*" and "*lockdown*" in Stage 2, finally to material "*shortage*" and port '*congestion*' in Stage 3. In Stage 1, the CSR focused on the corporate regular business operations, involving "*fee*", "*breakbulk*", "*fruit*", and "*vegetables*". In Stage 2, CSR focused more on "*sustainability*", "*eco-friendly*". In the post-epidemic era, CSR of Stage 3 focused more on "*innovation*" and "*carbon-neutral*". MM has played an irreplaceable role in this crisis. "*Alliance*" appeared in Stage 1 and Stage 2 of MM. This indicates that shipping companies have proactively adopted strategic alliances during the epidemic to improve their competitive advantage. MM focused on the investment in technology, which appeared in Stage 1 and Stage 3 of "*blockchain*" and "*investment*" in Stage 2. Seafarers are the frontline workers who sail the ships to transport containers, and shipping companies paid more attention to "*crew*" and "*seafarers*" during Stage 2 when the epidemic was most severe. From Stage 2 to Stage 3, shipping companies were actively concerned about carbon and sulfur emissions, despite the adverse effects of port closures, cargo delays, blank sailing, and port congestion.

4.3. Concordance Analysis

To further understand the meaning of keywords, concordance analysis can derive the actual context of keywords, shown in Appendix A. Next, the three stages of concordance analysis were conducted to conclude shipping enterprises' crisis response and evolution pattern.

Stage 1: Pre-/early-Crisis. "*Novel*" appears in the form of "*Novel coronaviruses*", a sign of the coming crisis. In the early stages of the outbreak, some port offices in mainland China were closed. However, to ensure the regular operation of the logistics, more OOCL offices in China were reopened and published on the official website, see the concordance of "*reopened*" (for example, "*Shanghai Already Reopened*", "*Tianjin Already Reopened*"). "*Fee*" includes "*B/L Release Elsewhere Fee*", "*Amendment Fee in case of changing Original Bill to Seaway Bill*", "*Amendment Fee in case of changing Payment location*", and "*Late fee of delayed payment*", which belong to the "*fee waiver*". "*Securities*" involves General Average of MV Northern Jupiter of ONE. "*Alliance*" as an effective form of cooperation, the shipping companies were making alliances, as usual, to bring innovative product solutions. TradeLens, a digital platform jointly developed by IBM and Maersk, is based on blockchain technology, permitting increased transaction volumes and efficient information exchange. MSC shipping line has piloted the use of blockchain technology on more than 200 routes worldwide, calling more than 200 ports, to improve supply chain speed, efficiency, transparency, security, and quality of service. CMA CGM Foundation and OM Foundation launched the MouvTaVie project, committing to promoting and "*training*" young people between the ages of 18 and 25 who are "*not in education, employment or training*". The CCG was remarkably prescient in anticipating possible humanitarian "*crises*" from the outbreak, preparing unique supplies, and providing maritime and logistical support. Collectively, in Stage 1, shipping lines were aware of "*Novel coronaviruses*", but still developed blockchain technology, alliances, and social training.

Stage 2: Crisis-in-Progression. COVID-19 was identified as a pandemic, indicating the epidemic entered the stage of development. "*Home*" included "*place of delivery*", "*consumer stay home*", "*crew return home*", and "*office-based employees work from home*". Political pressures, shareholder intentions, and changing consumer behavior have pushed "*sustainability*" front and center. A key component of sustainability was digitalization and making green gains, such as fashion supply chains. The roots of sustainability were primarily supply chain efficiency and investment choices made by companies. Collaboration was the only way for the shipping industry to move to a sustainable platform. Besides, companies also disclosed sustainability in terms of environmental protection, human rights protection, increasing trade benefits, and improving ship recycling (for example, "*restructuring*", "*eco-friendly*"). "*Fashion*" stood for "*fashion supply chain*", which grew increasingly complex and needed resilience and flexibility due to the COVID-19 pandemic. Moreover, as fashion retailing is about speed and the ability to meet insatiable consumer demand, the fashion supply chain must react quickly. The pandemic has upended supply chains. As a result of the global lockdown, demand for commodities such as apparel has plummeted. In contrast, demand for other products—from personal protection (for example, "*masks*") to flour and toilet paper—has peaked. This shift has challenged the visibility, timeliness, and flexibility of the company's supply chain. The global lockdown, causing crews to work onboard beyond their contracted period, has triggered a crew change crisis that has severely damaged crews, physical and mental health. With IMO setting a 0.5% cap on the sulfur content of the fuel, MAERSK was aggressively preparing to ensure that ships switched from heavy oil to low sulfur fuels. At the same time, the companies were actively exploring and experimenting with a range of alternative energy sources and technologies to accelerate decarbonization. During the epidemic, children were also one of the main concerns of the shipping company, mainly among the "*cargo users*", "*recipients of donations*", and, not least, children's education. The pandemic presented the need for flexibility and "*resilience*". "*Delays*" represented "*delayed delivery of goods*". Due to port "*congestion*" and sanitary and phytosanitary (SPS) requirements, companies and customers were eager to build "*resilience*" and stability. In light of the extraordinary impact of the COVID-19 pandemic, some shipping lines launched "*blank sailing*" program to match market demand. The above scenario illustrated the direction of the company's restructuring operations and stakeholder investments.

Stage 3: Post-COVID-19-Era. Following the development of the vaccine, most seafarers were vaccinated and entered the post-epidemic era. Container equipment (in the Asia Pacific), "*truck*" and "*truck*" driver were "*insufficient*", an industry-wide challenge. Supply chain security, cyber security, patient safety, drug safety, vaccine safety, and food safety were issues requiring high priority at this stage. "*Delays*" in the delivery of goods remained commonplace. MAERSK and MSC increased technological innovation (for example, Supply Chain Management Digital "*innovation*"), digital and cultural transformation, and upgrading to enhance the company's competitiveness. "*Blockchain*" as a superior technology can overcome IT roadblocks and lack of resources, offering access to new visibility and optimization technologies to foster greater collaboration and trust across the global supply chain. To reflect diversity and inclusion, companies encouraged more women (for example, company employees, truck drivers) to participate in the transportation and logistics field. Responding to customer demand, companies needed to transport medicines, PPE, vaccines to "*patients*", which were extra inputs for companies. The shortage of containers and congestion at ports pressured companies to conduct business. Methanol-fueled, low sulfur oil-powered vessels were a crucial pathway for decarbonization logistics to achieve carbon neutrality goals. Handling last-mile shipments to end-consumers were significant during the epidemic. Based on the epidemic considerations, multimodal transport has become more common, especially block trains to provide an economical, efficient, fast, and fixed timetable sustainable solution for cargo transportation. The call for cooperation among all supply chain players and the strengthening of ongoing cooperation with partners, suppliers, and customers remained an intrinsic requirement of the industry. "*Recovery*" of Suez Canal (Ever Given), "*recovery*" service, the coronavirus "*recovery*" curve, and the post-pandemic "*recovery*" demonstrated the expectation of crisis recovery.

5. Discussion

5.1. Theoretical Implications

The COVID-19 pandemic posed an unprecedented threat to the shipping industry. If not properly handled, it could affect the movement of goods in the global logistics supply chain and jeopardize an organization's image [63]. The central contribution of this study is to provide an in-depth analysis of the container shipping industry's strategic response to the pandemic crisis by integrating theories of crisis management, CSR, and MM.

First, from the perspective of the crisis process [33], COVID-19 has had a more severe impact on the shipping industry than both the financial crisis and the SARS virus [64]. In Stage 1, the shipping industry characterized the virus as Novel coronaviruses, and container shipping companies disclosed the scope of the crisis, including "*detention*", "*extension*", "*difficulties*". Entering Stage 2, a pandemic outbroke, in which global "*lockdown*" was seen everywhere in the context of a pandemic, leading to "*work from home*", "*cargo delays*", and "*blank sailing*". In Stage 3, due to the port congestion, goods could not be loaded or unloaded in time and postponed, which led to the logistics equipment being "*insufficient*", such as container "*shortage*". Based on the view of the crisis process, it is proposed that the crisis response is an evolutionary process as the crisis develops and that the evolutionary crisis response theory can provide theoretical reference for future studies of the shipping industry. The lexical patterns evolving from shipping lines public discourse from January 2020 to July 2021 illustrate the changes in crisis response of container shipping companies, elucidate an evolutionary process, and convey a positive corporate image to stakeholders.

Second, as for CSR, in Stage 1, shipping lines were rich in enthusiasm (for example, "*passion*"), securing cargo supply (for example, "*breakbulk*", "*fruit*", "*vegetables*"). In Stage 2, in addition to responding to the crisis, companies were also paying more attention to "*sustainability*". "*digitalization*", "*green gains*", "*collaboration*", "*environmental protection*", "*human rights protection*", "*ship recycling*", and "*fashion supply chain*" were all fundamental ways to achieve sustainable development in the shipping industry. Supporting "*children*", especially in education, can effectively reflect CSR of shipping lines[65]. In Stage 3, companies encouraged more "*women*" to participate in company production and create jobs for women. "*Innovation*" was one of the aspects of CSR in this period, such as "*digitalization*", "*big data*", "*end-to-end integrated supply chain*", "*alternative fuels*", "*real-time end-to-end supply chain visibility*". In addition to Stage 2, Stage 3 focused on environmental protection (for example, "*decarbonization*", "*carbon-neutral*"). Therefore, the CSR analysis of the above three stages shows that the business behavior of shipping lines is in line with the inherent requirements of CSR, which lays the theoretical foundation for the subsequent study of CSR in the shipping industry[66].

Third, MM continued to function in the three stages, and the evolution of MM was as follows. In Stage 1, MM focused on "*security*", "*blockchain*", "*training*", and "*alliances*". In Stage 2, travel restriction, "*lockdown*", and the constant change in local regulations and requirements brought about a crew change crisis. Based on this, shipping lines recognized seafarers as key workers, established gold standard health protocols, enhanced communication between ship operators and charterers, and strengthened the safety of seafarers. The alliance emerged in Stage 1 and Stage 2, with the Maersk and MSC Alliance, Global Industry Alliance (GIA), Ocean Alliance being the manifestations of the alliance. In response to the epidemic, alliance members were constantly aligning their resources to match the moving demand of the global shipping market. In Stage 3, there was a renewed emphasis on "*blockchain*" and "*security*", which appeared in Stage 1. In other words, MM presents "*alliance*" liaison and human factors as the key crisis responses, which centralizes the industry nature in the very industry's crisis responses.

Moreover, there is no strict boundary between crisis management, CSR, and MM, and they can complement and transform each other [32]. In this paper, the theories of crisis management, CSR, and MM are deeply explored and relearned in the context of cooperation and institution discourses.

5.2. Practical Implications

The findings highlight the significance that the container shipping companies instill in their public discourses information and emotions for projecting an excellent corporate image [63]. Both the continuation of the epidemic and the rebound in seaborne trade posed challenges to the container shipping industry, including equipment and container shortages, less reliable service, crowded stalls, longer delays and hold-ups, crew change crisis [20]. Moreover, the significance in shipping lines' public discourse about fulfilling corporate social responsibility as crisis responses is worth of great attention, for instance, in this study, the shipping industry positively responded to the IMO's call for efforts to adapt to climate change and the urgent need to decarbonize and find alternative fuels to reduce emissions.

Container shipping companies have learned a lot from and responded to the COVID-19 crisis; this has been revealed from the corporate discourse. Crew management, company operations, and market operations should develop contingency plans and provide institutional safeguards. Companies can explore long-term mechanisms that allow employees to work from home and on-site and conduct performance evaluations to reduce the risk of employees being infected and travel costs. Companies could establish a psychological assistance platform to provide psychological assistance, such as psychological counseling, to crew members and company employees to relieve tension [2]. The shipping industry, governments, and international organizations are called upon to ensure seafarers are key workers and create favorable conditions for prioritizing the vaccination of seafarers. The epidemic has changed consumers' shopping habits, strengthening investment in electronics, digitalization, and automation to increase efficiency and cost savings [65].

As proposed by Chris Trelawny, Chief, Sub-Division for Maritime Development, Technical Cooperation Division, IMO, "Shipping truly is the most international of industries and the need for dialogue and liaison—cooperation if you will—between all those countries is vital to ensure that standards are set, regulations are enforced and that a level playing field is maintained."[67]. It is more vital in worldwide crises for the industry to strengthen the cooperation between international organizations (for example, The Baltic and International Maritime Council, International chamber of shipping), national governments, and port authorities. As the epidemic accelerated, there were port congestion and equipment shortages [68]. The grounding of Ever Given led to congestion in the Suez Canal. IMO, as an organizer, need to enhance communication and cooperation between member states and port authorities. In response to port congestion, port authorities can explore different modes of ship access and cargo handling to ease port congestion. Besides, to achieve Sustainable Development Goal 5.5: "Achieve gender equality and empower all women and girls", IMO can call on international organizations, shipping companies, port authorities, cargo handling, and port operations to create more employment opportunities for women.

Climate change and the implementation of environmental protections can be the threading themes of crisis responses on the part of shipping lines, which help build up the CSR image of the companies [69]. The contingencies and emergencies posed by such world crises as COVID-19 have not compromised the CSR awareness of the shipping lines, rather they can be the chances for further research on sustainability as a way out of crisis. On 1 January 2020, the global sulfur regulations came into force. For ship exhaust emissions, maritime authorities strengthen the inspection and monitoring mechanism and impose penalties for non-compliance with the requirements. MAERSK announced their desire to achieve carbon neutrality by 2050. IMO should set specific emission reduction routes rather than leaving them to large shipping companies alone to decide. Simultaneously, large shipping companies can actively research and develop low-carbon emission ship main engines and low-carbon and low-sulfur fuels following IMO greenhouse gas emission requirements and the Paris Agreement [70].

5.3. Limitations and Future Research Directions

Horizontally and longitudinally, as this study examined textual data collected from large global shipping companies, some limitations should be acknowledged. Only the top 10 global container shipping companies were studied in this survey. Although the sample was well representative of interested researchers, smaller shipping companies were excluded from the study. Due to space limitations, we only tested data from January 2020 to July 2021. Perhaps the results would be more interesting if data for each month were extracted for comparative analysis. In addition, there may be cultural differences in response strategies to crises in different countries and sectors.

Despite these limitations, this study constructed a research framework of crisis management, CSR, and MM through the lens of textual analysis of press releases and advisories issued by companies in the Pre/early-Crisis, Crisis-in-Progression, and Post-COVID-19-Era. The study results depicted the evolutionary process of emergency response strategies and crises. We encourage future research conducted across industries to derive crisis response strategies. This study can conclude that crew change crisis, ship fuel, environmental protection, organizational resilience, and international maritime cooperation are research hotspots and point to future research.

6. Conclusions

COVID-19 will not end in the short term and will affect the international shipping industry in the long term; moreover, COVID-19 is not the last worldwide crisis the international shipping industry has to face. This study proves that the research method and the theoretical framework constructed by text analysis are valid and can elucidate how the shipping industry responds to the outrageous crises such as the epidemic in discourse. The extracted positive and negative keywords revealed textual characteristics and emergency response strategies on the part of shipping lines in the Pre/early-Crisis, Crisis-in-Progression, and Post-COVID-19-Era. The inclusion of the themes of pursuing sustainability in the shipping lines' responses to such worldwide crisis as COVID-19 is out of the common knowledge of crisis management but reveals the commitment and strategies on the part of the industry. The findings provide a reasonably comprehensive picture of the efforts made by large container shipping companies to respond to COVID-19 and the measures taken to soothe stakeholders. This paper extends and relearns crisis management, CSR, and MM theories through integrating the fulfilling of cooperate social responsibilities in maritime management as the cooperate crisis responses, thus proposing the integrity of the three topics of crisis management, CSR, and MM. In addition, management recommendations are provided for shipping company management, IMO, and port authorities. This paper also explored the future research hotspots and research methods.

The shipping industry is complex, and there is still uncertainty due to the epidemic. However, the shipping industry has proven its resilience and indispensability in the global economic recovery. This study provides an initial attempt to explore the crisis response strategies of the container shipping industry as the invitation to further and wider studies of the international shipping dynamics and mechanics in dealing with the world rife with crises and adversities.

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Appendix A

Table A1. Keyword-in-context: exemplary statements for the themes.

Corpora	Themes	Concordance Lines
Stage 1	Crisis	1. In order to facilitate the prevention and control of **novel** coronaviruses and better accommodate the customers' needs in cargo arrangement during this period, we hereby announce specific policy on container free use in **mainland** China: All Extra DND amount incurred during 24 January 2020 to 9 February 2020 will be waived. (COSCO) 2. OOCL operational update: Extended free time period in **detention** calculation. (COSCO) 3. Can we apply for **extension** of container free time or cost reduction in ports outside China? (COSCO)
	CSR	1. During this special time, is there any policy regarding fee waiver? (COSCO) 2. Come and speak to our experts and find out more about how we can meet your **breakbulk** needs. MSC will be at Stand C61 at **Breakbulk** Mumbai, held 27–28bFebruary. (MSC) 3. At MSC we think big and with great passion for our work we manage the whole process. (MSC) 4. Today, **fruits** and **vegetables** make up a high percentage of goods carried in refrigerated containers ("reefers") by CMA CGM. (CCG)
	MM	1. While the **reopening** of some offices is still pending for approval by local authorities, please see below the latest status of our offices in China: Beijing Already **Reopened**. (COSCO) 2. The owners have appointed Stichling Hahn Hilbrich (Hamburg & London) as Average Adjusters. They will be arranging for the collection of General Average securities from parties concerned in cargo, containers and bunkers. (ONE) 3. Sailing on more than 200 trade routes, calling at over 500 ports, MSC's shipping line is pioneering the use of **blockchain** to further increase speed, efficiency, transparency, **security** and service across the supply chain, both through its pilot initiatives and in technology projects sponsored by multiple carriers. (MSC) 4. By launching the #MouvTaVie project, the CMA CGM Foundation and OM Foundation commit to promoting and supporting the integration and **training** of around thirty young people between the ages of 18 and 25 who are "not in education, employment or training" (NEET). (CCG)
Stage 2	Crisis	1. In addition to this, the **COVID-19 pandemic** has further amplified the vulnerabilities of fashion brands, making it imperative for them to incorporate resilience and flexibility within their supply chains. (Maersk) 2. Our office-based colleagues have shown their **resilience** by adapting to working from **home** to the extent possible, and we have tried our best to support this change, mentally and physically. (Maersk) 3. The **lockdown** in Europe and the US caused a sudden drop in consumer spending in many sectors. (CCG) 4. To cope with the challenge of **COVID-19 pandemic**, COSCO SHIPPING Lines have implemented blank sailings program of OCEAN Alliance services for June to July 2020. (COSCO)

Table A1. *Cont.*

Corpora	Themes	Concordance Lines
Stage 2	CSR	1. We are delighted to welcome UNICEF as one of our partners and to be able to play our part in supporting UNICEF's efforts to help **children** worldwide. (CCG) 2. It will also free up space at **origin** factories and warehouses and avoid excess **inventory** at site, bringing cargo closer to destination markets and alleviating the risk of **congestion** or closure at ports of discharge. (MSC) 3. With the deployment of these modern, **eco-friendly** and highly efficient new vessels, Yang Ming will be able greatly enhance its service quality and deliver more excellent service to global customers. (YM)
	MM	1. Our single biggest challenge has been to relieve our **seafarers** after their tour has ended, due to travel restrictions, closed borders and the constant change in local regulations and requirements. (Maersk) 2. In addition, the company is engaging with potential vendors to investigate new solutions such as alternative **fuels** that would help to minimize and one day eradicate CO2 and other greenhouse gas (GHG) emissions from shipping fleets. (MSC) 3. Our situation within the Ocean **Alliance** continues to provide us significant advantage, and ensures that we are able to offer a broad, high-quality service network to our customers. (COSCO) 4. In addition, we remain committed to our broader **sustainability** agenda, including our role in multiplying the benefits of trade, contributing to halving food loss and improving the ship **recycling** industry. (Maersk) 5. Kaplan, Goldman and Kellan all agree that the **recovery** from the coronavirus will be a time of significant change for supply chains globally with customers keen to build both **resilience** and stability. (Maersk) 6. THE Alliance will continue to closely monitor the market situation and respond efficiently by restructuring their service scheme to meet market demand. (ONE)
Stage 3	Crisis	1. Equipment **shortages** remain an industry-wide challenge in Asia Pacific. 20-foot dry containers are sufficient, but 40-foot and 45-foot- dry containers are short. 40-foot non-operating reefer is also **insufficient**. (Maersk) 2. Further expansion in shipping powered by innovation for higher levels of **security**, operational efficiency and greater customer satisfaction through the introduction of more sustainable transport solutions as well as through the Group's commercial offer. (CCG) 3. The pandemic-induced **lockdown**, dynamic geopolitics and economic conditions have led to shipping **delays** and port **congestion**, leading to an escalation of D&D costs for importers. (Maersk) 4. ICS also pointed out that shipowners could face liabilities and costs if **vaccinations** are not delivered and highlighted, as it has happened before, the serious consequences for **seafarers'** physical and mental well-being. (MSC) 5. The supply chains for pharmaceutical customers include high levels of complexity and we understand the need for reliability as well as the importance of products getting to the **patients**. (Maersk)
	CSR	1. The carbon footprint per vessel also can be reduced by 52% with greater energy efficiency, enabling HMM to accelerate the pathway towards **decarbonization**. (HMM) 2. The Transport and logistics industry has traditionally been male dominated. Due to this, we're increasing the representation of **women** in Maersk at all levels. (Maersk) 3. The CMA CGM Group is contributing to international solidarity efforts by delivering oxygen production units, containers of liquefied oxygen and specialist medical equipment by **truck**, plane and ship. (CCG)

Table A1. *Cont.*

Corpora	Themes	Concordance Lines
Stage 3	MM	1. This intercontinental **block** train has been able to stand by its schedule, delivery times and swift transit clearance on time, creating firm ground for further expansion of transcontinental transit. (Maersk) 2. TradeLens is an open and neutral industry platform underpinned by **blockchain** technology, supported by major players across the global shipping industry. (HL) 3. By achieving this, Maersk will be able to pilot a scalable, **carbon-neutral** solution to customers and incentivise manufacturers to scale the production of new, sustainable **fuels**. In other words, create a market that does not exist yet. (Maersk) 4. Handle **last-mile** deliveries to the end consumer. (Maersk)

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Article

Resilience Analysis of Maritime Silk Road Shipping Network Structure under Disruption Simulation

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Abstract: As an important hub in the maritime transportation system, ports are vulnerable to events such as terrorist attacks, security accidents and bad weather. The failure of port nodes to function effectively affects the connectivity and efficiency of the shipping network and impedes trade between countries. In view of this, in this paper, we constructed the Maritime Silk Road shipping network based on route data and used transmissibility and diversity to represent the resilience of the network and nodes. Then, we analyzed the variation characteristics of resilience using disruption simulation and identified 9 dominant nodes and 15 vulnerable nodes that could help to accurately determine the factors that affect the resilience of the MSR shipping network structure. The results show that the Maritime Silk Road shipping network structure is vulnerable, and the failure of ports to function has different effects on network transmissibility and diversity. In terms of node transmissibility and diversity, there are differences in the resistance of port nodes to interventions. In addition, the failure of dominant ports to function and the emergence of vulnerable ports are significant factors that weaken the resilience of the network structure. When dominant ports are interrupted, this greatly affects the resilience of the network structure. It is necessary to reduce the possibilities of the failure of dominant ports. Vulnerable ports are weaknesses in the resilience of the network structure, which weaken the ability of the network to function. The centrality of these ports should be strengthened, and their relation to regional and trans-regional links should be enriched. The research results provide a scientific basis for ensuring the structural resilience of the Maritime Silk Road shipping network.

Keywords: disruption simulation; Maritime Silk Road; shipping network structure resilience; dominant port; vulnerable port

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1. Introduction

The 21st Century Maritime Silk Road (MSR) initiative has promoted all-around co-operation between China and countries along the road in maritime transportation and port construction, providing strong support for the sustainable development of the world economy. As important hubs in the maritime transportation system, ports closely connect the whole world and play a crucial driving role in regional economic development [1]. In terms of total volume, more than 80% of goods are transported by sea, which accounts for 70% of the total international trade [2].

The MSR includes most countries in Asia, Europe, Africa and Oceania, covering a large area. The efficiency of its shipping network is very important for the stability of trade and economic development in countries along the MSR and worldwide. However, in the process of cargo transportation, the MSR shipping network often faces various uncontrollable emergencies, especially under the current background of rampant terrorism, epidemics and natural disasters. These emergencies lead to the closure of some ports, thus affecting the cargo shipment of relevant ports and routes [3]. When the disturbance is great, it may have a domino effect on other parts of the network system [4], which may eventually cause the whole shipping network to face the risk of low efficiency and the delayed delivery of goods. Therefore, the resilience of the MSR shipping network structure should be improved without delay.

The resilience of a network structure refers to the ability of a network system to restore, maintain or improve the original network performance and functions when dealing with emergencies [5]. In the research concerning network structure resilience, scholars have used indicators that describe network structure characteristics in complex network theory to measure the resilience of networks, including social networks, supply networks, urban networks, transportation networks, and so on [6–8]. Previous studies have found that network efficiency, diversity and connectivity can effectively evaluate the resilience of a network structure [9–12], but there is no unified evaluation method at present.

In the process of evaluation, random and deliberate attacks are mostly used [13,14]. Then, the attenuation degree, influencing factors and multiple optimization strategies concerning the overall resilience of different network structures are discussed. In addition, disruption simulation is also a common quantitative analysis method for network structure resilience, which can distinguish between dominant and vulnerable nodes [15]. This is significant to ensure network transmission efficiency and improve network stability.

Within the current background of political instability and frequent natural disasters along the MSR, studying the resilience of the MSR shipping network structure using disruption simulation can help predict the operational capability of the network to resist potential risks. This type of research would also enable targeted network resilience improvement strategies to be more scientific. Therefore, in this study, we took the MSR shipping network as an example and used complex network theory to explore the variation characteristics of the network and node resilience under an external impact.

The paper is structured as follows. In Section 2, a review of the related literature is provided. In Section 3, the research methods and objects are introduced. In Section 4, the MSR shipping network structure resilience is analyzed using a disruption simulation. In Section 5, we analyze the characteristics of key ports and propose strategies to enhance resilience. Finally, the conclusions and implications are provided in Section 6.

2. Literature Review

With the frequent occurrence of natural and man-made disasters, the concept of resilience is gradually emerging. Resilience was first proposed by Holling [16] in the study of ecosystems. The two core parts of this concept are the ability of the system to resist negative impacts created by attacks and the ability of the system to recover from damage. Since then, the concept of resilience has been introduced into other disciplines, including engineering, psychology, sociology and economics [17–19]. Many effective evaluation frameworks have been derived from different disciplines. Cimellaro et al. [20] constructed a framework to measure the resilience of communities on different spatial and temporal scales. Zou and Chen [21] proposed a resilience assessment framework for the transportation power system affected by hurricanes and combined this with a Monte Carlo simulation to evaluate the resilience of the two systems. Zhao et al. [22] proposed an evaluation index system for distribution network resilience by considering multi-energy coordination and constructed an ANP model for evaluation.

Combined with complex network topology, the quantification of network resilience using specific indicators is also a commonly used method [23]. The resilience of a network depends not only on the importance of disturbed nodes but also on the overall connectivity of the network [24]. Crespo et al. [25] evaluated regional network resilience by calculating degree distribution and degree correlation and pointed out that a core edge structure would weaken the resilience of a network. Dixit et al. [26] evaluated the resilience of a supply chain network based on network structure parameters, including network density, centrality, connectivity and network size. By studying the topological characteristics of water supply networks, Meng et al. [27] concluded that network topology greatly impacts network resilience. Additionally, they proposed that connectivity, efficiency, centrality, diversity, robustness and modularity are the key topological indicators in the evaluation of network resilience. Zhang et al. [28] proposed the evaluation of node and edge resilience to comprehensively evaluate the resilience of an entire network. Zhou and Hou [29] established an analysis framework of spatial simulation, resilience evaluation and spatial planning, and the node degree, structural hole, betweenness and clustering coefficients were used to evaluate resilience.

Resilience is widely used in transportation networks, including road networks, railway networks, subway networks, aviation networks, maritime networks, etc. It is often evaluated based on network topology. Network topology mainly affects network resilience in terms of resistance and recovery capability [30]. The definition of resistance is similar to robustness. The robustness of a network refers to its ability to maintain its functionality under attacks or failures [31]. Robustness analysis of the transportation network could help identify the regions sensitive to the regional and large-scale failure of the network [32]. Wandelt et al. [33] proposed a new exploration search technique for a computationally efficient attacking model and analyzed the robustness of air transportation networks. Peng et al. [34] designed statistical indices based on complex network theory and employed four attack strategies, including a random attack and three intentional attacks (i.e., degree-based attack, betweenness-based attack and flux-based attack), to evaluate the robustness of the three typical cargo ship transportation networks. Chen et al. [35] investigated the robustness of China's air transport network (CATN) over 40 years due to random failures and targeted attacks. The results showed that when subjected to targeted attacks, CATN's robustness is dominated by 20% of airports. The direct measurement of robustness can be carried out through random or deliberate node removal. Studies often compare the impact degrees under different deliberate attack sequences and identify the number of nodes that must be removed in order for the network to break down.

In terms of the resistance of network resilience, IP and Wang [36] abstracted cities and roads as nodes and edges, respectively, and evaluated node resilience using the weighted average of reliable channels with other urban nodes in the network. Qi et al. [37] used four indicators, including the network efficiency and sensitivity, to analyze the resilience of a bus–subway hybrid traffic network. The resilience of a transportation network is also closely related to its recovery strategy, such as the recovery sequence of multiple interrupted nodes and edges [38]. Improving the path diversity and redundancy can significantly improve the resilience of a transportation network [39]. Dunn and Wilkinson [40] analyzed the impact of adaptive and permanent strategies on the resilience of the European airport network. The results showed that the adaptive recovery strategy could effectively improve network resilience. Zhang et al. [41] used the nearest link method to change the topology of an expressway network and simulated the addition of lines to improve the redundancy and resilience of the system.

The research regarding the resilience of shipping networks is similar to that of other transport networks. Mou et al. [42] evaluated the resilience of the maritime crude oil transportation network from qualitative and quantitative aspects using complex network indicators and a resilience model. Asadabadi and Miller-Hooks [43] proposed a stochastic two-level game model that considered port competition and cooperation to evaluate and improve the resilience of the global port network. Wan et al. [44] constructed the effectiveness index of network recovery strategies based on the triangular model of resilience loss to improve the shipping network's resilience.

At present, there is no unified evaluation method for evaluating network structure resilience, and there are few studies on the resilience of the MSR shipping network, which is of great significance in planning the layout of ports and routes along the MSR. Drawing on the relevant research results concerning resilience in different fields, in this paper, we used transmissibility and diversity to reflect the resilience of the shipping network structure. Then, the dominant ports and vulnerable ports within the scope of the MSR were identified, and the characteristics of the ports were analyzed. Finally, we put forward suggestions to enhance the resilience of the MSR shipping network structure, providing scientific references for the sustainable development of the MSR shipping network.

3. Research Method and Object

3.1. Research Method

3.1.1. Research Framework

Figure 1 shows the research framework of this study.

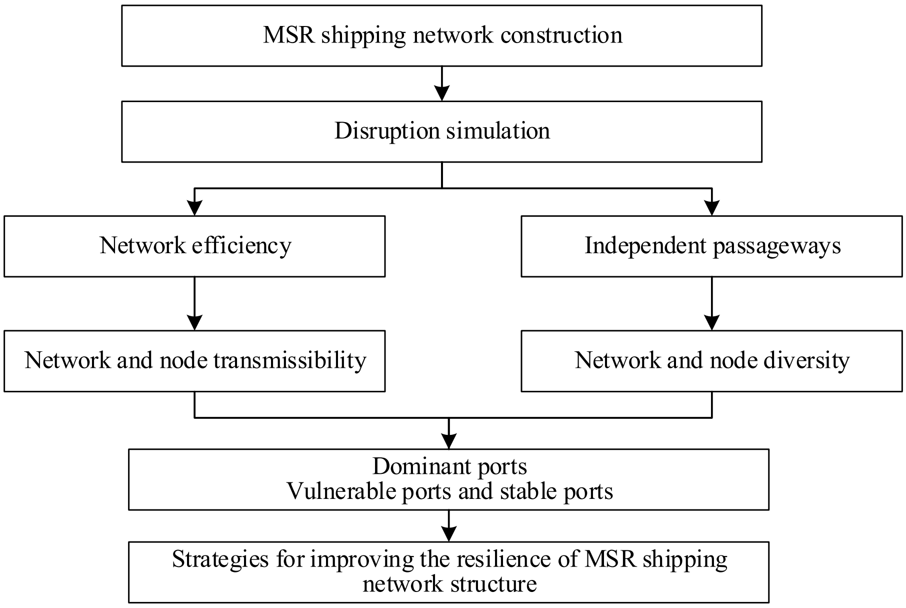

Figure 1. Research framework of this study.

3.1.2. Network and Node Transmissibility

Transmissibility describes the ability of element flow diffusion in complex networks, and it is mainly related to the shortest path length between nodes. High transmissibility means that port nodes in a network can quickly exchange information, goods, capital and other elements. This will promote the coordinated development of ports and countries along the MSR and enhance its resistance to emergencies.

In this paper, the index of network efficiency is used for the quantitative evaluation of network transmissibility, which is defined as the transmission function realized directly based on the network [15]. Many scholars have demonstrated the accuracy of network efficiency as a measurement of resilience through empirical studies [9]. It is expressed as:

$$E_g = \frac{1}{N(N-1)} \sum_{i \neq j} \frac{1}{d_{ij}} \quad (1)$$

where E_g represents the network efficiency, and $0 \leq E_g \leq 1$. d_{ij} is the shortest path length between port i and j. N is the total number of port nodes.

The calculation method for node transmissibility is similar to network transportability. The difference is that it only reflects the transmissibility efficiency between a node and all other nodes, that is:

$$E_i = \frac{1}{N-1} \sum_{i \neq j} \frac{1}{d_{ij}} \quad (2)$$

3.1.3. Network and Node Diversity

Diversity is the description of network fault tolerance. The diversity of a network mainly refers to the existence of multiple connection paths between nodes. When a certain path is affected by emergencies, other paths ensure the normal operation of the network [45] to effectively maintain the stability of the network. Network diversity is very important for real networks such as the shipping network. When port nodes or links fail to operate due to emergencies and restoring the port or route to the normal state as soon as possible, an effective way to ensure the normal operation of the network is to connect two port nodes by another path. Therefore, the diversity of the MSR shipping network depends on whether there are alternative routes between the two ports.

Due to many nodes, the number of paths between nodes will be huge. Moreover, there will be many extremely long paths, which is seriously inconsistent with the actual situation. In this paper, we used the average number of independent passageways proposed by IP and Wang [36] as references to measure the network diversity. The independent passageway between nodes is a set of paths without the same edge connected between nodes. It is worth noting that the calculation of this indicator is a heuristic. Many scholars have used it to study resilience in many fields, such as ecological networks [8], urban networks [15], road-bridge networks [46], road networks [47,48]. These studies have proved the feasibility and effectiveness of this indicator. The calculation formula is as follows:

$$V_g = \frac{\sum\limits_{i \neq j} n_{ij}}{N(N-1)} \quad (3)$$

where V_g represents the average number of independent passageways. n_{ij} is the number of independent passageways between port i and j.

The calculation method for node diversity is similar to that used for network diversity. For node diversity, the connectivity diversity between a node and all other nodes needs to be calculated, that is:

$$V_i = \frac{\sum\limits_{i \neq j} n_{ij}}{N-1} \quad (4)$$

The idea of finding independent passageways is similar to finding the shortest paths between all node pairs. We can combine the Dijkstra algorithm to calculate the number of independent passageways. Algorithm 1 shows the calculation process of network and node diversity.

Algorithm 1: Network and Node Diversity

1: Input network G, which contains N nodes and E edges.
2: Create a N*N matrix K, all values n_{ij} are 0.
3: **for each** i, j **do**
4: Set the initial path number $k = 0$.
5: **if** $i = j$ **then**
6: n_{ij} = 0
7: **Else if** there is no path between i , **then**
8: let n_{ij} be equal to k
9: **Else** Compute the shortest path from i to j using the Dijkstra algorithm, and set $k = k + 1$.
10: Delete all edges on path k, and go to Step 7.
11: **end if**
12: **end if**
13: **end for**
14: Compute V_g and V_i using Equations (3) and (4).
15: **return** the matrix K, V_i and V_g.

3.2. Research Object

The MSR focuses on the route from China's coastal ports to Europe and Africa through the South China Sea and the Indian Ocean and the route from China's coastal ports to the South China Sea to the South Pacific. It covers East Asia, Southeast Asia, South Asia, West Asia, East Africa, Oceania, the Mediterranean, Europe and other regions. Within this scope, we constructed the MSR shipping network and made the following assumptions:

(1) One city corresponds to one port, and each port city is one node.
(2) If port *i* and *j* are two calling ports adjacent to any routes, it is considered that there is edge between the ports. The direction of the route is the direction of the edge.
(3) The number of routes attached to port *i* and *j* is taken as the weight of the edge between port *i* and *j*.

The route data were derived from the Container Forecaster of Drewry in 2019. After screening, 179 ports were finally obtained, and a directed weighted network was constructed.

4. MSR Shipping Network Structure Resilience under Disruption Simulation

The network disruption simulation mainly considered the impact of emergencies on different port nodes. The disruption simulation took the port node in the network as the attack object. A network disruption scenario was simulated under the failure of one port node at a time, and 179 port nodes were attacked successively. The port nodes immediately failed when attacked, and all of the edges connected with them were removed simultaneously.

4.1. Network Transmissibility and Diversity Analysis

Firstly, the network transmissibility and diversity of the MSR shipping network in the initial state without interference were calculated, which were 0.3256 and 3.3488, respectively. Then, the adjacency matrix of the MSR shipping network under different port failure scenarios was simulated, and the resilience of the network structure was measured. Figure 2 shows the network transmissibility and diversity changes when all port nodes fail individually in sequence. The simulation found that when an emergency occurs, the path length and the number of alternative paths between ports will be affected. Additionally, the cost related to the connections between ports will increase, and the number of alternative paths will decrease, which will lead to the simultaneous attenuation of the resistance, response and resilience of the network structure. Some ports greatly impact the transmissibility and diversity of a network, meaning that they have important roles alongside their roles as bridges. Additionally, some ports are also important for path diversification.

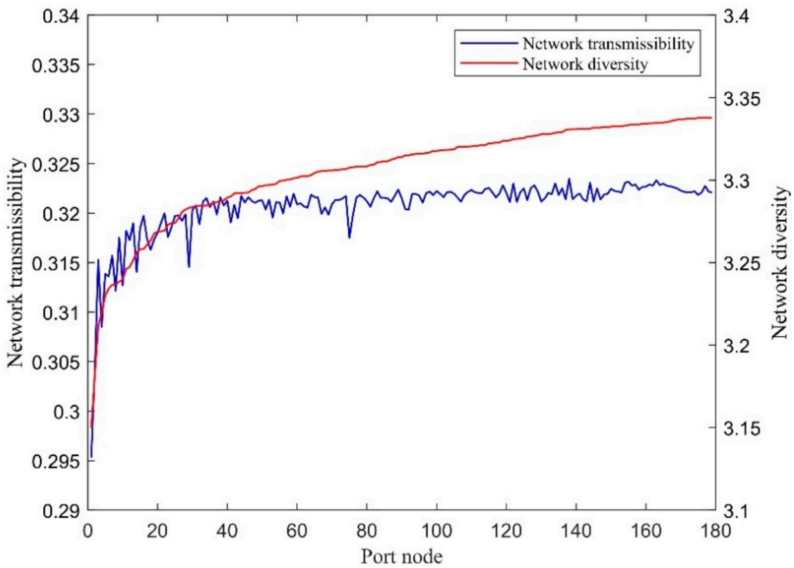

Figure 2. Network resilience when all port nodes individually fail in sequence.

In addition, the two broken line trends in Figure 1 display certain differences. Some ports greatly impact the transmissibility or diversity of the network, and some have small impacts. This may be due to the limitation of marine geography and channel distribution to a certain extent. There are fewer routes that directly connect multiple regions, which makes the role of ports different. However, in smaller regional shipping networks, the degree of the impact on network transmissibility and diversity tends to be synchronous.

Figure 3 shows the resilience of the East Asian regional shipping network, including China, Japan, and South Korea.

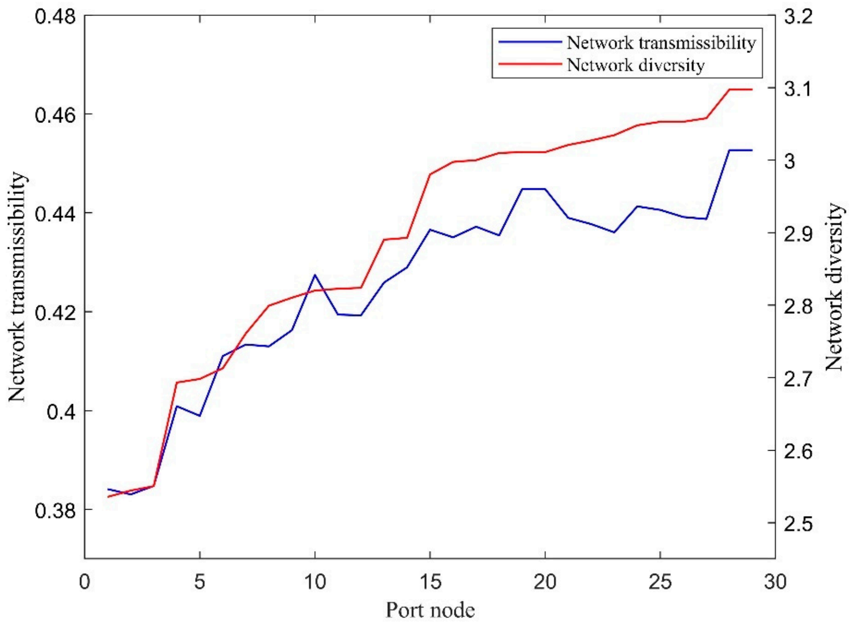

Figure 3. East Asian regional shipping network resilience when all port nodes individually fail in sequence.

The K-means algorithm adopts distance as the evaluation index of similarity. The closer the distance between two objects is, the greater the similarity. So, we adopted the K-means algorithm to cluster ports and regarded the values of the transmissibility and diversity of the MSR shipping network when different ports failed as "distance". The K value is obtained by the elbow method. The ports were divided into five levels. The results are shown in Table 1 (only the first three levels are shown).

Table 1. Classification of ports along the MSR based on K-means clustering algorithm.

Category	Ports (Based on Network Transmissibility after Port Failure)	Ports (Based on Network Diversity after Port Failure)
First level	Singapore, Port Klang, Colombo	Singapore, Port Klang
Second level	Ambarli, Piraeus, Bremerhaven, Tanjung Pelepas, Busan, Rotterdam, Port Moresby, Ningbo-Zhoushan, Hong Kong	Ambarli, Tanjung Pelepas, Busan, Jeddah, Colombo, Rotterdam, Ningbo-Zhoushan, Port Said, Tauranga, Hong Kong
Third level	Algeciras, Antwerp, Auckland, Brisbane, Dar Es Salaam, Dammam, Davao Tanjung Priok, Durban, Kaohsiung, Guangzhou, Port of Hamad, Hamburg, Jeddah, Jebel Ali, Kimbe, Koper, Rabaul, Lae, Le Havre, Maputo, Melbourne, Jawaharlal, Nehru, Qingdao, Port Said, Shanghai, Shenzhen, Kobe, Sohar, Tauranga, Tianjin	King Abdullah Port, Algeciras, Antwerp, Auckland, Piraeus, Bremerhaven, Brisbane, Dammam, Damietta, Durban, Kaohsiung, Port of Hamad, Hamburg, Gioia Tauro, Le Havre, Lyttelton, Marsaxlokk, Mundra, Port Moresby, Melbourne, Jawaharlal Nehru, Qingdao, Genova, Shanghai, Shenzhen, Tianjin, Valencia

It can be seen that the ports at the first, second and third levels are located on the main line of the MSR. Additionally, they basically include the necessary places for all the important transportation channels. For example, the Singapore, Port Klang and Tanjung Pelepas ports are located in the Strait of Malacca. The Colombo port is an important transit port for Asian, European and African countries. The Jeddah port and Port Said are located along the Bab el-mandeb strait to the Suez Canal. The Jebel Ali and Algeciras ports are located in the Strait of Hormuz and Gibraltar, respectively.

Further analysis shows that there are ports that simultaneously have a high impact on network transmissibility and diversity. In this paper, these key ports related to resilience are referred to as dominant ports. We regard the ports in Table 1 belonging to the first and second levels of influence for network transmissibility and diversity as dominant ports. There are nine dominant ports in total, namely Singapore, Port Klang, Colombo, Ambarli, Tanjung Pelepas, Busan, Rotterdam, Ningbo-Zhoushan and Hong Kong. Singapore, Port

Klang and Colombo are the three most dominant ports, with each ranking in the top five ports related to the impact of port failure on network transmissibility and diversity.

4.2. Node Transmissibility and Diversity Analysis

The resilience level of port nodes will decrease in varying degrees due to the failure of different ports. Still, there is generally only one port that has the greatest interference with a certain port. This scenario is called the maximum disturbance state of the port. Then, we compared the changes in node resilience level for each port under the maximum disturbance state, and the results are shown in Figure 4.

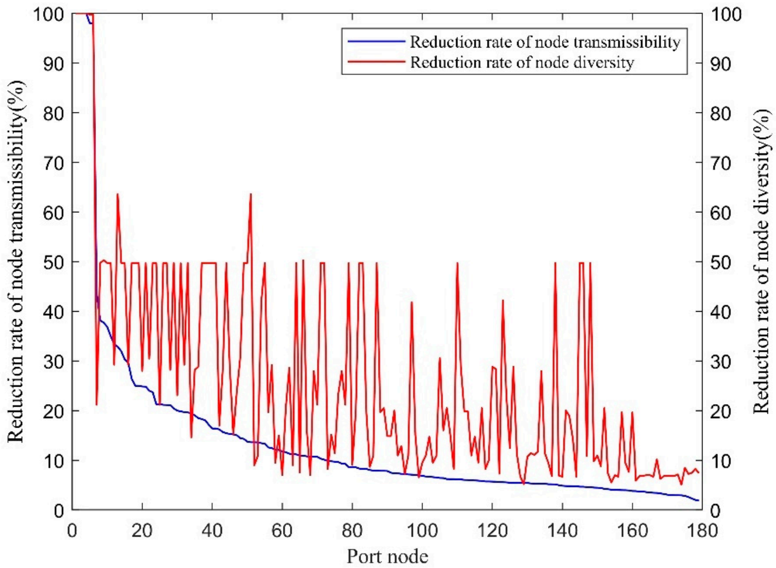

Figure 4. Port node resilience reduction under maximum disturbance state.

It can be found that the reduction degrees of port node transmissibility and diversity under the maximum disturbance state are different. The transmissibility and diversity of the Abidjan, Vigo, General Santos and Yangon ports under the maximum disturbance state both drop to 0, which is because these four ports are only connected to one port in the MSR shipping network. When their connected port fails, the four ports will be isolated. Some ports, such as Singapore port, Port Klang and Colombo port, show strong resistance to intervention.

From this perspective, another type of key port related to resilience in the MSR shipping network is called a vulnerable port. The resilience level of this kind of port easily and significantly declines with the failure of other ports. The emergence of vulnerable ports weakens the resilience of the MSR shipping network in response to emergencies. Similarly, based on the reduction rate of port node transmissibility and diversity under the maximum disturbance state, all ports were divided into five levels using the K-means clustering algorithm (the smaller the level is, the greater the average value). In this way, we obtained two classification results. Additionally, the ports in the first and second levels were regarded as vulnerable ports: the Ahus, Abidjan, Vigo, Gothenburg, General Santos, Yangon, Beira, Penang, Gdynia, Kuching, Lisbon, Male Island, Surabaya, Subic Bay and Townsville ports. In addition, for better comparative analysis, the ports in the fifth level were regarded as stable ports, which have strong abilities to resist external intervention.

5. Characteristic Analysis of Key Ports and Resilience Improvement Strategy

5.1. Characteristic Analysis of Dominant Ports

The failure of dominant ports has a great impact on the resilience of the network structure and is also the root cause of the significant reduction in the resilience level of all other port nodes, as shown in Table 2. Specifically, the failure of the Singapore port was shown to have the greatest interference on the resilience level, with more than 20% of the port nodes along the MSR being affected by its failure, followed by Port Klang. Additionally, their interference scope was not shown to be limited to Southeast Asia, which has a certain impact on many different geographical regions.

Table 2. The influence proportion of dominant ports on other ports' resilience.

Dominant Ports	Port Transmissibility Influence Proportion	Port Diversity Influence Proportion
Singapore	20.67%	20.67%
Port Klang	13.41%	9.50%
Colombo	3.91%	2.23%
Rotterdam	3.35%	3.91%
Ambarli	3.35%	3.91%
Ningbo-Zhoushan	3.35%	2.79%
Busan	2.23%	1.68%
Tanjung Pelepas	2.23%	1.12%
Hong Kong	1.68%	1.12%

The dominant ports occupy prominent positions in the network structure, which makes them more vulnerable to attacks and poses a threat to the sustainable development of the MSR shipping network. Next, we analyzed the characteristics of dominant ports in terms of the structural location and connection strength of port nodes. Node degree was used to measure the structural location, reflecting the breadth of the connection between this port and other ports. The weighted degree measured the connection strength, reflecting the depth of connection between a certain port and other ports.

Then, a Pearson correlation analysis was conducted. The correlation coefficients between the network transmissibility when a port fails and the degree value and weighted degree value of a failed port node were −0.864 and −0.770. The correlation coefficients between network diversity when a port fails and degree value and weighted degree value of failed ports were −0.932 and −0.796, and the significance levels were all less than 0.01. The results show that the larger the degree value and the weighted degree value of a port node, the greater the influence on the network transmissibility and diversity when a port node fails. From the perspective of structural position, the degree values of dominant ports are large. Additionally, they are transfer stations for multiple ports, which means efficient connectivity and diversified connections can be realized. From the perspective of connection strength, these ports are not only connected with many ports but are also closely connected, and the flow of goods is also frequent.

5.2. Characteristic Analysis of Vulnerable Ports

The port node resilience measurement was based on the maximum disturbance state involving the port that had the greatest impact on it. Therefore, during the characteristic analysis, the factor of the sailing distance between two ports increased. The analysis method used was similar to that described in Section 5.1. The structural position and connection strength of a port node were still measured using the degree value and weighted degree value. The sailing distance refers to the actual sailing distance between the port and the corresponding failed port under the maximum interference state, obtained using Netpas Distance software. At the same time, by comparing the regional distribution of ports connected with vulnerable ports and stable ports, we further analyzed the connection characteristics.

According to the correlation analysis, when a port node is in the maximum disturbance state, the correlation coefficients between the reduction rate of port node transmissibility and degree value, weighted degree value and sailing distance are −0.582, −0.491 and −0.368, respectively. The correlation coefficients between the reduction rate of port node diversity and degree value, weighted degree value and sailing distance are −0.598, −0.496 and -0.326, respectively. The results show that the actual sailing distance is not the constraint factor of the port's ability to resist external intervention. The structural position of a port node is an important explanation for the formation of the vulnerable ports, and the connection strength has little influence on the port node resilience.

In terms of the geographical distribution of the MSR, it is divided into eight regions: East Asia, Southeast Asia, South Asia, the Middle East, the Mediterranean coast, northern and western Europe, eastern and southern Africa, and Oceania. Based on the classification of vulnerable ports and stable ports in Section 4.2, we then compared the regional distribution of their connected ports. The results are shown in Table 3. Due to a large number of stable ports, only ports whose degree value was above 20 are shown.

Table 3. Regional distribution of ports that are connected with vulnerable ports and stable ports.

Ports		Number of Connections in the Same Region	Number of Connections in Different Regions
Stable ports (Degree value is higher than 20)	Singapore	9	53
	Port Klang	4	44
	Colombo	9	24
	Jeddah	6	23
	Piraeus	11	12
	Busan	15	7
	Tanjung Pelepas	6	30
	Rotterdam	10	16
	Hong Kong	12	14
	Jebel Ali	9	17
	Le Havre	7	13
	Ningbo-Zhoushan	16	10
	Qingdao	14	6
	Port Said	15	12
	Shanghai	15	9
	Shenzhen	14	12
Vulnerable ports	Ahus	2	0
	Abidjan	1	0
	Vigo	0	1
	Gothenburg	2	0
	General Santos	1	0
	Yangon	0	1
	Beira	2	1
	Penang	1	1
	Gdynia	2	0
	Kuching	2	0
	Lisbon	1	1
	Male Island	2	1
	Surabaya	1	1
	Subic Bay	1	1
	Townsville	2	1

The reason stable ports can resist external interference better is that they have more diversified shipping links. These ports not only form a cluster closely connected with the same region but also have rich trans-regional connections as supplements. This greatly enriches the shipping trade of ports, enabling the ports to maintain diversified and efficient transportation routes in the case of emergencies.

By contrast, vulnerable ports have exposed characteristics of the lack of connection in the same region and the lack of trans-regional connection. Most vulnerable ports have shipping links with only one or two ports in the same region. Additionally, the Ahus, Abidjan, Gothenburg, General Santos, Gdynia and Kuching ports do not have trans-regional shipping links. Therefore, such ports rely heavily on their linked core ports, and the failure of core ports will greatly interfere with port node resilience.

5.3. Strategies for Improving the Resilience of MSR Shipping Network Structure

Dominant ports and vulnerable ports are of great significance to the resilience of the MSR shipping network structure. When the dominant ports are interrupted during emergencies, this has a strong effect on the resilience of the network structure. Therefore, it is necessary to reduce the possibilities of the failure of dominant ports. The vulnerable ports are weaknesses to the resilience of the network structure, which weakens the ability of the network to deal with the impact of emergencies. The characteristics of vulnerable ports showed that the main reasons vulnerable ports affect the resilience of the network structure include the low centrality of port nodes, weak links in ports in the same region and insufficient trans-regional shipping links. Therefore, it is necessary to enhance the resistance of vulnerable ports to intervention according to their characteristics. Based on the above analysis, the following strategies are proposed to improve the resilience of the MSR shipping network structure:

First, enhancing the security and emergency response capability of dominant ports is very important to ensure the resilience of the network structure. All the ports should formulate contingency plans and establish effective management systems to deal with natural disasters, bad weather and other emergencies. This will minimize damage to ports caused by emergencies and ensure the normal operation of ports. Furthermore, port management should provide an efficient emergency repair system for port construction according to different emergencies.

Second, the centrality of vulnerable ports should be strengthened, and the network structure should be optimized. Vulnerable ports are greatly affected under the maximum disturbance state because they have fewer trans-regional connections. Therefore, the container liner routes should be adjusted appropriately, and the transit business of general ports should be improved. It is also very necessary to enhance the strength of existing connections. In this way, the existing weak connections between ports can be transformed into strong connections to improve port centrality. When vulnerable ports maintain close connections with regional hub ports, they should avoid too many single connections and promote a regional port group that can develop into a complex spatial network structure.

Third, the diversity of trans-regional connections should be enriched. Due to the geographical limitations of the MSR, trans-regional connections play bridging roles in the whole network. The enrichment of trans-regional connections can greatly improve transport efficiency and capacity and enhance the resilience of the MSR shipping network.

Fourth, it is also necessary to appropriately improve the container throughput capacity of the adjacent ports of hub ports. When a hub port fails, the adjacent port will take on some transportation tasks. If the redundant capacity of the adjacent ports is insufficient, this will lead to the failure of the adjacent ports. In addition, the increase in throughput capacity should not be formulated blindly but should be coordinated with the hub port to avoid excessive throughput capacity caused by repeated port construction and the waste of social resources.

6. Conclusions

In this paper, transmissibility and diversity were used to represent the resilience of network and port nodes. Based on a disruption simulation, the variation characteristics of the resilience of the network and port nodes in the MSR shipping network in response to an external intervention were analyzed. Then, we analyzed the characteristics of key ports and identified the factors that affect the level of resilience in the network. Finally, suggestions were put forward to optimize the MSR shipping network structure in terms of resilience. The main conclusions of this paper are summarized as follows:

(1) Port failure will have an impact on the resilience of the Maritime Road shipping network structure, among which the failure of some ports has a great impact. Due to the limitation of marine geography and channel distribution to a certain extent, the effects of port failure on network transmissibility and diversity are different.

However, in smaller regional shipping networks, the degree of impact on network transmissibility and diversity tends to be synchronous.

(2) The reduction rate of the transmissibility and diversity of port nodes under the maximum disturbance state are different, and a few ports are isolated under the maximum disturbance state.

(3) Dominant ports are transfer stations for multiple ports, which enable efficient connectivity and diversified connections. Additionally, they have closer connections and more frequent cargo flows. When a port node is in the maximum disturbance state, the sailing distance from the corresponding port is not the main factor that affects the resilience of a port node. In addition, stable ports are more diversified in terms of regional and trans-regional links, especially trans-regional ones.

(4) Through the analysis of network connection characteristics regarding dominant ports and vulnerable ports, to improve the resilience of the MSR shipping network, we need to confirm the security and emergency response capability of dominant ports, strengthen the centrality of vulnerable ports and enrich the diversity of trans-regional connections. In addition, appropriately improving the container throughout capacity of the adjacent ports of hub ports will also help to improve network resilience.

Taking the MSR shipping network as an example, this paper discussed the resilience of the network structure during disruptions. The research results can provide a valuable reference for ensuring network transmission efficiency and improving network stability. However, there are still some limitations to this study. When using an independent path to measure diversity, some potential paths may be lost in the calculation process. Furthermore, in a real-life situation, there will be dynamic changes in routes and cargo transfer during the recovery of a shipping network. In the future, combined with the route weight, we can further consider the redistribution of cargo volume after the external impact on the shipping network to realize a dynamic study on the resilience of shipping networks.

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Global Maritime Container Shipping Networks 1969–1981: Emergence of Container Shipping and Reopening of the Suez Canal

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Abstract: This study applied graph theory to conduct an empirical analysis of the evolution of global maritime container shipping networks, mainly focusing on the 1970s. In addition to analyzing the change in overall structures of the networks over the long term (from the 1970s to the present) and midterm (in the 1970s), the authors examined the changes in the container shipping networks before and after the reopening of the Suez Canal in 1975. As a result, it was confirmed that the initial single polar network structure, in which New York and other North American ports were placed at the center, changed to a multipolar structure, finally forming a hub-and-spoke structure. Subsequently, the authors confirmed discontinuous changes in inter-regional density from 1975 to 1976 caused by an increase in the average number of ports of call in 1976, because the recession caused by the first oil crisis in 1973 decreased the maritime container shipping demand, and the reopening of the Suez Canal caused a surplus of containerships. This study would contribute to accumulating empirical knowledge on the vulnerability analysis of the present and future maritime container shipping networks.

Keywords: maritime container shipping (MCS); network analysis; Suez Canal (SC); weighted network; graph theory; 1970s; liner service (LS)

1. Introduction

Maritime shipping is one of the oldest means of transport. It has changed form, such as vessel type and cargo handling, but is still an important means of cargo transport. Among them, maritime container shipping (MCS), which was introduced in the middle of the 20th century, rapidly gained an important position. Since its emergence, MCS has continued to expand, except during periods of recession, and constitutes an integral part of the current globalized world economy. However, during its development, MCS has experienced many obstacles, including the closure of the Suez Canal (SC), two oil shocks, pirate attacks, economic downturns, and damage or shutdown of individual ports because of accidents, natural disasters, and strikes, but has overcome them by changing the network structure flexibly in some instances. Among them, the closure of the SC from 1967 to 1975 was considered to have a significant impact on maritime shipping, including MCS, because the SC is a key infrastructure located along the trunk routes connecting Europe and East Asia (EA). The year 2021 will record that the SC was closed in March owing to the grounding of a containership (*Ever Given*). Although the closure of the SC in 2021 lasted only around a week, many impacts on global logistics were argued in the world's mass media. Therefore, discussing the impact of the closure of the SC until 1975 would provide useful lessons to the present global economies. In recent studies on MCS, network science techniques have been applied to assess its vulnerability and to understand its structural features. However, owing to a lack of available data, these studies mainly focused on the post-1970s period. In other words, changes in the network structure in the era of the emergence of MCS, and the impact of the reopening of the SC in 1975, have not been sufficiently verified. Therefore, there is a lack of sufficient empirical knowledge on these events.

This study analyzes global MCS networks in the 1970s, focusing mainly on the emergence of MCS and the reopening of the SC. We use a data source (Recent World Container Services (最近の世界コンテナ船就航状況) before 1977; World Container Fleets and Their Services (世界のコンテナ船隊および就航状況) after 1978) compiled by Nippon Yusen Kaisha (hereafter, the NYK report) for developing liner service (LS) network data of global MCS, mainly in the 1970s, and apply graph theory. Through the analyses, we reveal the developmental process of MCS in the 1970s and the changes of the network structures after the reopening of the SC.

The remainder of this paper is organized as follows: Section 2 reviews the relevant literature. Section 3 describes the data, models, and methods used in this study. Section 4 confirms the entire history of the development of the global MCS network since its emergence of MCS in the 1970s to 2016 to give a broader perspective to place our analysis. Section 5 focuses on the detailed changes in the era of the emergence of MCS, mainly in the 1970s, and Section 6 assesses the impact of the reopening of the SC in 1975 on the entire MCS. Finally, Section 7 summarizes the conclusions and future perspectives.

2. Literature

Transport network analysis based on graph theory is particularly common in the field of air and land transport. Research on the comprehensive network analysis of maritime shipping has also accumulated in recent years. Liu et al. (2018) [1] applied a weighted ego network analysis to visualize the spatial heterogeneity of maritime networks at the global and local levels. Fang et al. (2018) [2] proposed an automatic identification system (AIS)-based approach to understanding maritime network dynamics before and after international events, namely, military conflict between India and Pakistan, economic sanctions on Iran, and government elections in Sri Lanka. Toriumi and Watanabe (2012) [3] analyzed vessels sailing in the region where piracy and armed robbery incidents occurred using piracy data provided by the International Maritime Bureau and Lloyd's data on vessel movement. Wang et al. (2017) [4] analyzed the container service network of liner shipping companies in 2004, 2009, and 2013 between Taiwan and mainland China using a weighted network. Yu et al. (2019) [5] analyzed the tanker network structure and predicted flow changes by oil price variations using a systems-based approach to construct a maritime transportation network based on trajectory data.

Moreover, regarding the network analysis focusing on the characteristics of the present global MCS network, Hu and Zhu (2009) [6] analyzed the LS network in 2006 and calculated ports with good connectivity by setting edges between all ports in the same LS. Ducruet and Notteboom (2012) [7] further extended Hu and Zhu (2009) [6] using Lloyd's data on the movement of containerships between ports in 1996 and 2006 and compared the network structures at each time point. Ducruet et al. (2010) [8] analyzed Northeast Asian liner networks in 1996 and 2006 by hierarchical clustering with indicators such as hub dependence, degree distribution, and foreland diversity index. Pan et al. (2019) [9] applied the eigenvalue decomposition method to the LS network of the seven largest MCS companies in 2005. Cheung et al. (2020) [10] also used eigenvector centrality and frequency weights for the analysis. Kawasaki et al. (2019) [11] applied the proximity centrality method to intra-Asian LS data in 2016. In most of these analyses, the topological aspects of the MCS network were identified by connecting the ports in a sequential order that vessels called at in each LS. However, because the MCS network is composed of multiple LSs with multiple port callings, in-service container movements and movements via transshipment between LSs should be distinguished. Therefore, this study considers not only a graph of direct linkages (GDL) by setting edges along the shipping movements but also a graph of all linkages (GAL) in the LS, similar to Hu and Zhu (2009) [6], Ducruet et al. (2010) [12], and Ducruet and Notteboom (2012) [7].

Some studies have focused on network vulnerabilities. For example, Stergiopoulos et al. (2018) [13] applied critical infrastructure dependency modeling to the positioning data of containerships from 2015 to 2017 obtained from the AIS. They evaluated the dependence between ports on vessel movement routes and identified routes and ports with high risk. Toriumi and Takashima (2012) [14] estimated the importance of global chokepoints, including the Bosporus, the SC, the Bab el-Mandeb Strait, the Hormuz Strait, the Malacca Strait, and the Panama Canal, by calculating the chokepoint rate from Lloyd's vessel movement database. Wu et al. (2019) [15] used the LS data of 100 major MCS companies to estimate the impact on the network if the three major chokepoints, including the Malacca Strait, the SC, and the Panama Canal, were blocked and it was discovered that the transport capacity of the entire network could be reduced by 10% to 50%. Lhomme (2015) [16] assessed the global vulnerability of world maritime shipping and identified the most critical ports by evaluating the importance of vertices or edges in a graph. Viljoen and Joubert (2016) [17] simulated the impact of large-scale service reconfiguration affecting priority links by evaluating link-based disruption strategies on a global MCS network constructed from AIS data. They found that the network is by and large robust to such reconfiguration and that some specific strategies for cutting links could decrease the efficiency of the network at the same time. These model simulations are useful for predicting potential failures of maritime networks in the future, whereas the accumulation of empirical knowledge is essential for verifying the validity of the models.

Furthermore, some studies conducted an empirical analysis of past changes. Ducruet et al. (2015) [18] used Lloyd's List records on vessel movements from 1890 to 2008 and analyzed the change in the structure of the global maritime shipping network. Similarly, Ducruet (2017) [19] used Lloyd's data on the inter-port movement of vessels from 1977 to 2008 to calculate the hierarchical structure of ports. Tsubota et al. (2017) [20] used the same data and focused on South Asia from the perspective of the end of the British Empire. They revealed the impact of independence in each country on intra-regional shipping between ports in these countries. The results of these studies provide a significant amount of information on the long-term transition of the entire network structure. However, as the analyses were conducted without distinguishing vessel types, the information obtained on containerships was limited. Ducruet et al. (2016) [21] applied a network analysis on maritime flows connecting cities of the world over the period of 1950–1990 using shipping movement data from Geopolis and Lloyd's databases. From this study, they suggested that the largest cities have maintained their dominance in terms of network centrality and geographical reach. However, this study did not focus on MCS. Ducruet et al. (2019) [22] used fully cellular MCS data from 1977 to 2016 to investigate the evolution of inter- and intra-port vessel movements. In this analysis, they measured the average time that ships stay at or voyage between ports and demonstrated the acceleration of global shipping both within and between ports for 40 years. They indicated that larger ports performed better than smaller ones in terms of staying time and that navigating speeds in the longest and shortest shipping links were faster than others.

Meanwhile, some studies have focused on the impact of specific past events. Rousset and Ducruet (2020) [23] analyzed the impacts of historical events that caused port shutdowns, such as the Hanshin-Awaji Earthquake, the September 11 terrorist attacks on the United States, and Hurricane Katrina. As a result, it was confirmed that containerships were relatively sensitive to changes at import/export and transshipment ports because of such events, whereas the impact on the global MCS network was unlikely to spread because the regional MCS network absorbed the impact. Grenzeback and Lukmann (2008) [24] examined the transport sector's response to and recovery from Hurricanes Katrina and Rita and reviewed the influence of the disaster on the national-level movement of freight.

Xu and Itoh (2018) [25] focused on the Hanshin-Awaji Earthquake and analyzed its impact on container cargo flow. They found that, although the ports of Tokyo and Yokohama were not directly affected by the earthquake, extensive diversions of container traffic to the port of Busan occurred from these ports, not only from the port of Kobe.

The 1970s is known as the era of two oil shocks and the reopening of the SC in the maritime shipping market. These events affected the cost of fuel and shipping distance. Some studies on these events have focused on their economic effects from the perspective of historical economics. Feyrer (2021) [26] estimated the effect of distance on trade and the effect of trade on income in the events of the closure of the SC in 1967 and its reopening in 1975 by using IMF trade data. He suggested that the elasticity of trade with respect to the shock is larger when estimated on closure compared with reopening. Parinduri (2012) [27] investigated the relationship between trade and economic growth by observing the impact of the closure of the SC using the gravity model and found that trade led to higher economic growth rather than trade trends before and after the closure. However, these studies did not analyze the structural changes in MCS. Even though the influences of the reopening of the SC on distance and income were smaller than those of the closure, the network structure of MCS can be greatly changed for the reopening of the SC.

Based on the above discussion, we conduct an empirical analysis of the emergence of global MCS using LS data around the 1970s. In particular, we focus on the impacts of the reopening of the SC in 1975, which is thought to have had a significant impact on the MCS network. In the analyses, we use two kinds of LS data, which were preliminarily compiled as the LS network, as will be explained in Section 3, to focus more on the LS network structure, including both GDL and GAL networks. This study aims to accumulate useful knowledge for the methodology of vulnerability analysis and empirical results on MCS in the 1970s, suggesting future impacts on the global MCS network of partial failures in the network.

3. Data, Methods, and Models

3.1. Data

This study first prepares the global LS network data at 30 time points. Among them, the LS network data at 28 points from February 1969 to December 1995 are acquired from the NYK report, which was compiled based on Lloyd's data, and those in the two other time points (2003 and 2016) are from the MDS containership databank. The data include information on the LS of both full-container and semi-container ships, such as the operating companies, ports of call, their orders, frequencies, names of containerships, deadweight tonnages of the vessels, and maximum loadable number of containers in twenty-foot equivalent units (TEU), as shown in Figure 1. In contrast to pure vessel movement data, such as Lloyd's, these databases were preliminarily compiled on an LS basis and thus enable more precise analyses of the LS network.

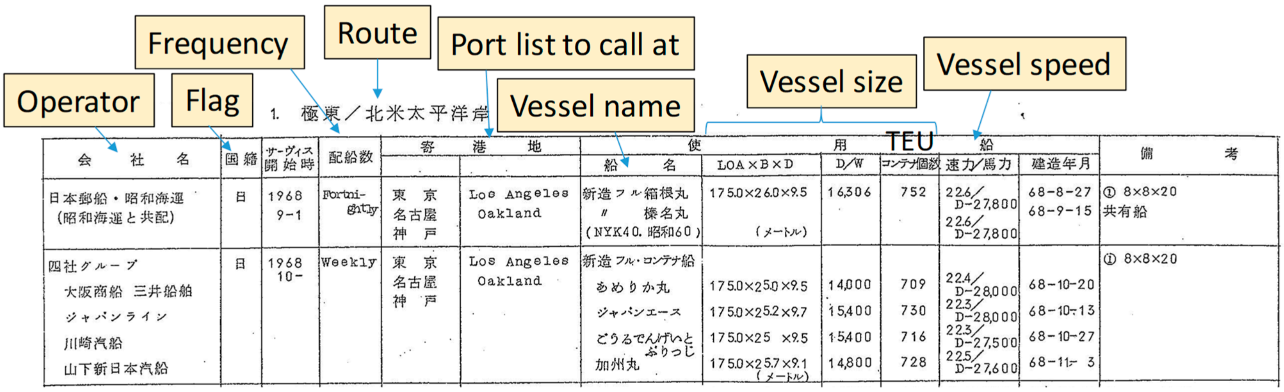


Figure 1. Sample of NYK report (issued in February 1969).

As the NYK reports were published in paper format, they should first be digitized in the same format as the MDS data. First, we exclude the data points for which volumes are obviously lower than those of nearby years; consequently, 16 data points are selected to be as equal as possible in terms of time interval. Subsequently, errors are eliminated from the data at each data point selected in the previous step. It is notable that, as clearly stated in the NYK reports, the data from 1981 to 1995 did not include regional routes, such as intra-Asian and intra-European routes. Specifically, as shown in Figure 2, the number of ports included in the data as of 1986 and later is un-naturally small. Similarly, the number in 1979 is smaller than in the years before and after. Therefore, considering that the objective of the study focuses on the analysis in the 1970s, the dataset of eight time points, namely, February 1969 (which represents the first half of the year), January 1971, 1973 (which represents the whole year), 1975, 1976, 1981, 2003, and 2016, is finally selected for the analysis. Note that although the data as of 1981 are included in the following analyses, they cannot be used for intra-regional analysis.

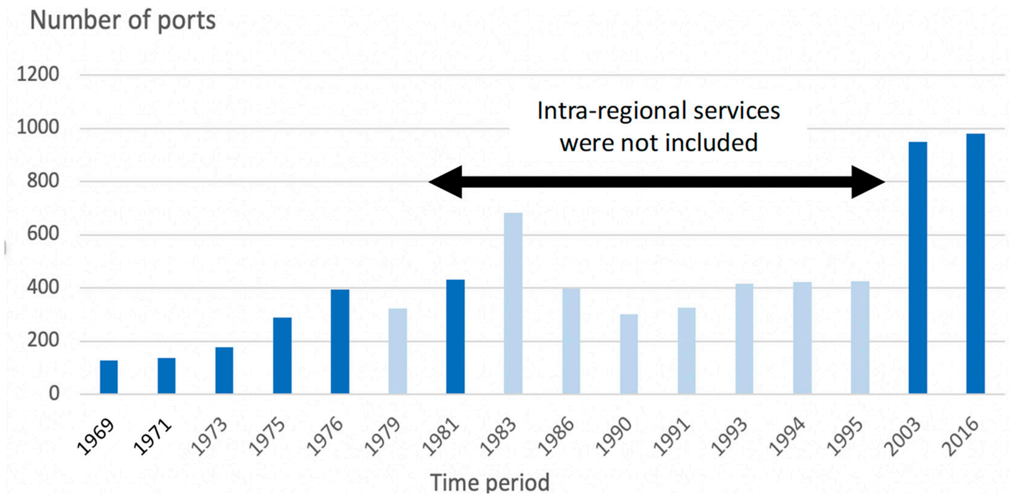


Figure 2. Number of container ports included in the data at each selected time point.

3.2. Methods

We apply graph theory to the above LS network data; namely, degree, density, and betweenness centrality are used as the indices in the network analysis.

Degree is the number of edges extending from one node, whereas *density* is the probability of the existence of edges between nodes in a network, defined as

$$D = \frac{m}{n(n-1)} \tag{1}$$

where D is the density, n is the number of nodes, and m is the number of edges.

Centrality is an index that measures the importance of each node in a network. In this study, betweenness centrality, $C_B(v)$, representing whether each node is located on the shortest path of the pairs of other nodes as defined in Equation (2), is used, considering the characteristics of the global MCS to form the hub-and-spoke structure:

$$C_B(v) = \sum_{s \neq v \in V} \sum_{\neq v t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}} \tag{2}$$

where V is a set of nodes, σ_{st} is the total number of routes from node s to node t, and $\sigma_{st}(v)$ is the number of routes from node s to node t via node v. For the clustering method, modularity-based community detection [28], Q, defined in Equation (3), is adopted:

$$Q = \frac{1}{2m} \sum_{i \in V} \sum_{j \in V} \left(A_{ij} - \frac{k_i k_k}{2m} \right) \delta\left(c_i, c_j\right) \tag{3}$$

where A_{ij} is the (i, j) component in the network adjacency matrix, k_i is the degree of node i, m is the number of links ($m = \frac{1}{2} \sum_{i \in V} k_i$), c_i is the community to which node i belongs, and $\delta(c_i, c_j)$ is the Kronecker delta, which is 1 if $c_i = c_j$ and 0 otherwise. Equation (3) indicates that the community of each node is determined such that the density within each community ($\left(A_{ij} - \frac{k_i k_j}{2m}\right) \cdot \delta\left(c_i, c_j\right)$) is higher than that of the entire network, as well as the densities between different communities. To save calculation time, this study adopted the Louvain method [29], an iterative calculation algorithm of modularity optimization and community aggregation, to estimate communities, which is adopted as standard in NetworkX, a Python library.

3.3. Models

To analyze the network from multiple viewpoints, we develop six different models by changing the method of edge construction and the definition of the weight of edges in the network, as summarized in Table 1. There are two methods of edge construction: a graph of direct linkages (GDL) and a graph of all linkages (GAL). The GDL uses the movement of the containerships directly as edges. In contrast, the GAL connects all ports that are called at in the same LS, with edges. The GDL is suitable for the analysis of the movement network of containerships, such as the first and last ports of call in the region, whereas the GAL is suitable for the analysis of hub-and-spoke structures with transshipments because it can differentiate the ports that are connected in the same LS and the ports that are only connected indirectly through the transshipment port(s).

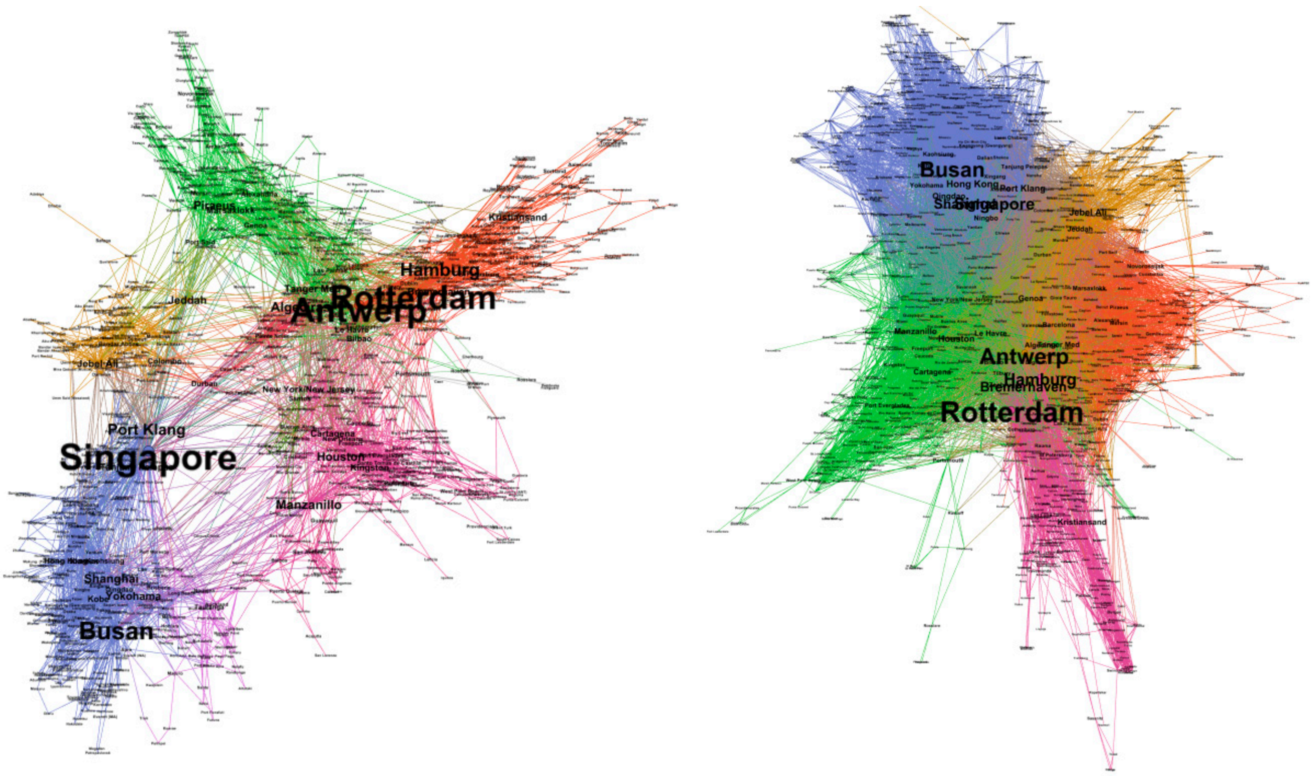
Table 1. Models used in this study with settings on edges.

Model Names	Edge Linkage	Edge Weight
GDL-1	GDL	None
GDL-2	GDL	Shipping Frequency
GDL-3	GDL	Shipping Capacity
GAL-1	GAL	None
GAL-2	GAL	Shipping Frequency
GAL-3	GAL	Shipping Capacity

GDL: a graph of direct linkages; GAL: a graph of all linkages.

The weights of the edges are defined in three different ways: no weight, shipping frequency, and shipping capacity. The non-weight model, in which the edges are all treated equivalently, is suitable for analyzing the geometry of the networks. The shipping frequency model represents the annual number of vessel movements between ports. The shipping capacity model represents the annual vessel capacities (which are acquired by multiplying annual frequency by average capacity per vessel) between ports. These weighted models can express the difference in the intentions of the inter-port connections based on the actual shipping situation.

Gephi visualization software is used, and Force Atlas is selected as the arrangement algorithm. The size of each node represents its centrality, and the color represents the community to which each node belongs. Figure 3 shows the visualization of the network developed by the GDL-1 and GAL-1 models for 2016, which is the latest year among the available data. In the GDL-1 model, the first and last ports of call in the region, such as Antwerp (Belgium) and Singapore, tend to gain more centralities as expected. Meanwhile, it seems that the GAL-1 model can focus more on the hub ports; however, it is not suitable for the analysis of the shape of the networks through visualization because the density of the network is too high. Hereafter, GDL models are used for the analysis of the movement network of containerships, whereas GAL models are used when focusing on LS networks and container transshipment.



GDL-1 model GAL-1 model

Figure 3. MCS network developed by the GDL-1 and GAL-1 models (2016).

4. Overview of the Global MCS Network Development (1969–2016)

This section gives an overview of the development history of the MCS network from 1969 to 2016, before focusing on it in the 1970s because understanding the entire history of the MCS network development from its beginning to the present is necessary for positioning the MCS network in the 1970s. Figure 4 tabulates the top 20 ports in the betweenness centrality with their scores estimated from the GDL-1 and GAL-1 models for each analysis year. The figure also marks three major regions: North America (NA), Europe, and EA. Figure 5 summarizes the number of nodes and edges and the network density in the GDL-1 model for each analysis year. The figure reveals that the number of nodes and edges monotonically increases, and the network density decreases from a long-term perspective.

The following analyses in this section focus on the MCS network at four time points, namely, 1969, 1981, 2003, and 2016, to give an overview of their development history. Figure 6 represents the MCS network developed by the GDL-1 model as of 1969, 1981, and 2003. The networks shown in Figures 3 and 6 indicate that the network centered on NA ports represented by New York (NY) in 1969 had changed to a multipolar structure with multiple regions and ports in 1981, then formed a hub-and-spoke structure in and after 2003, in which small ports were clustered around regional hub ports connected by a relatively small number of edges. Comparing the top 20 ports in the betweenness centrality estimated from the GDL-1 model as of 1981, which is shown in Figure 4, with those as of 1969, European ports became more central, and the number of EA ports in the top 20 ports increased. These findings also support our interpretation that the network, as of 1981, had become a multipolar structure. Furthermore, the betweenness centralities of EA ports were comparable to those of European ports in 2003, and the betweenness centralities of ports in other regions increased in 2016.

GDL-1 model

	1969		1971		1973		1975		1976		1981		2003		2016	
1	New York	0.541	New York	0.318	New York	0.343	New York	0.251	New York	0.217	Hamburg	0.115	Singapore	0.189	Singapore	0.148
2	Los Angeles	0.159	Kobe	0.163	Rotterdam	0.124	New Orleans	0.095	Rotterdam	0.115	Rotterdam	0.101	Antwerp	0.143	Antwerp	0.137
3	Callao	0.114	Rotterdam	0.119	Kobe	0.123	Baltimore	0.082	Le Havre	0.082	New York	0.086	Rotterdam	0.112	Rotterdam	0.134
4	Yokohama	0.111	Los Angeles	0.117	Los Angeles	0.073	Hong Kong	0.074	New Orleans	0.071	Leghorn	0.077	Busan	0.079	Busan	0.094
5	Liverpool	0.111	Hampton Roads	0.109	Le Havre	0.069	Hamburg	0.067	Hamburg	0.063	Antwerp	0.069	Hamburg	0.067	Hamburg	0.065
6	Rotterdam	0.101	Baltimore	0.107	Hong Kong	0.061	Le Havre	0.060	Singapore	0.052	Los Angeles	0.064	Yokohama	0.044	Port Klang	0.053
7	Kobe	0.093	Balboa	0.072	Hampton Roads	0.060	London	0.056	Liverpool	0.051	Houston	0.063	Port Klang	0.042	Algeciras	0.043
8	Hamburg	0.080	Rio de Janeiro	0.069	Rio de Janeiro	0.049	Charleston	0.055	Kobe	0.045	Le Havre	0.062	Piraeus	0.041	Manzanillo	0.042
9	London	0.071	Portland	0.058	Savannah	0.049	Philadelphia	0.054	Yokohama	0.045	Sydney	0.060	Gioia Tauro	0.040	Shanghai	0.038
10	Guayaquil	0.068	Bremerhaven	0.057	Genoa	0.048	Antwerp	0.053	Savannah	0.040	Singapore	0.058	Le Havre	0.040	Houston	0.037
11	Vancouver	0.067	Hamburg	0.055	Vancouver	0.047	Rotterdam	0.049	Los Angeles	0.040	Jeddah	0.057	Hong Kong	0.039	Piraeus	0.036
12	Baltimore	0.064	Liverpool	0.053	Liverpool	0.046	Los Angeles	0.049	Antwerp	0.039	Yokohama	0.055	Manzanillo	0.031	Jeddah	0.033
13	Bremerhaven	0.061	Sydney	0.048	Guayaquil	0.045	Savannah	0.040	Gothenburg	0.036	New Orleans	0.044	Bremerhaven	0.030	Yokohama	0.033
14	Antwerp	0.058	Salvador	0.048	Baltimore	0.043	Singapore	0.037	Vancouver	0.035	Montreal	0.042	New York	0.030	Tanger Med	0.029
15	Kingston	0.053	Callao	0.048	Leghorn	0.041	Houston	0.034	Hong Kong	0.033	Kobe	0.040	Felixstowe	0.027	Jebel Ali	0.029
16	Valparaiso	0.052	Yokohama	0.046	Hamburg	0.041	Kobe	0.032	Piraeus	0.031	Hong Kong	0.040	Valencia	0.025	Bremerhaven	0.028
17	Buenaventura	0.047	Puget Sound	0.042	Houston	0.040	Bremerhaven	0.030	Baltimore	0.031	Liverpool	0.035	Genoa	0.025	Kristiansand	0.027
18	Acajutla	0.047	Shimizu	0.039	Balboa	0.036	Norfolk	0.028	Port Klang	0.030	Vancouver	0.029	Durban	0.024	Tanjung Pelepas	0.025
19	Panama	0.046	London	0.037	New Orleans	0.035	Liverpool	0.027	London	0.028	Mumbai	0.028	Bilbao	0.024	Cartagena	0.025
20	Bremen	0.040	Seattle	0.036	Norfolk	0.034	Boston	0.025	Houston	0.027	Bremen	0.027	Houston	0.023	Kingston	0.024

GAL-1 model

	1969		1971		1973		1975		1976		1981		2003		2016	
1	New York	0.156	New York	0.124	New York	0.131	New York	0.144	Rotterdam	0.080	Hamburg	0.081	Antwerp	0.137	Rotterdam	0.099
2	Los Angeles	0.151	Los Angeles	0.113	Baltimore	0.090	Baltimore	0.118	Newyork	0.073	Rotterdam	0.078	Rotterdam	0.121	Antwerp	0.075
3	Liverpool	0.149	Baltimore	0.097	Los Angeles	0.077	Philadelphia	0.066	New Orleans	0.063	Antwerp	0.067	Singapore	0.063	Busan	0.071
4	Baltimore	0.120	Rotterdam	0.057	Houston	0.045	New Orleans	0.056	Baltimore	0.063	Leghorn	0.044	Hamburg	0.062	Hamburg	0.053
5	Rotterdam	0.110	Portland	0.049	Philadelphia	0.042	Antwerp	0.041	Antwerp	0.045	Liverpool	0.033	Busan	0.054	Singapore	0.052
6	Antwerp	0.109	Philadelphia	0.045	Benghazi	0.040	Hong Kong	0.040	Houston	0.045	Newyork	0.032	Hong Kong	0.041	Shanghai	0.042
7	Portland	0.087	Seattle	0.040	Vancouver	0.036	Savannah	0.036	Le Havre	0.044	Houston	0.032	Bremerhaven	0.028	Bremerhaven	0.041
8	Yokohama	0.074	Antwerp	0.039	Rotterdam	0.036	Charleston	0.035	Hamburg	0.044	Hong Kong	0.029	Piraeus	0.023	Hong Kong	0.026
9	Philadelphia	0.067	Vancouver	0.039	Seattle	0.035	Rotterdam	0.034	Philadelphia	0.036	Yokohama	0.028	Port Klang	0.022	Jebel Ali	0.024
10	Hamburg	0.049	Liverpool	0.036	Norfolk	0.030	Houston	0.033	Vancouver	0.026	Le Havre	0.028	Felixstowe	0.022	Port Klang	0.024
11	Norfolk	0.047	Kobe	0.032	New Orleans	0.030	Los Angeles	0.028	Liverpool	0.025	Singapore	0.027	Le Havre	0.021	Houston	0.023
12	Montreal	0.046	Hamburg	0.030	Le Havre	0.029	Hamburg	0.027	Norfolk	0.025	Kobe	0.026	Seattle	0.021	Manzanillo	0.021
13	Sanfrancisco	0.041	London	0.029	Portland	0.028	Le Havre	0.024	Kobe	0.024	Genoa	0.025	Yokohama	0.020	Qingdao	0.020
14	Nagoya	0.036	Yokohama	0.027	Liverpool	0.025	Benghazi	0.021	Los Angeles	0.022	Sydney	0.024	Barcelona	0.020	Kristiansand	0.020
15	London	0.031	Balboa	0.026	London	0.024	Seattle	0.020	Leghorn	0.020	Baltimore	0.024	Miami	0.019	Genoa	0.020
16	Hampton Roads	0.031	Sydney	0.022	Hong Kong	0.023	Genoa	0.018	Charleston	0.020	New Orleans	0.022	Trieste	0.018	Le Havre	0.018
17	Guayaquil	0.029	Melbourne	0.022	Kobe	0.022	Norfolk	0.018	Savannah	0.020	Oakland	0.020	Kaohsiung	0.017	Cartagena	0.018
18	Buenaventura	0.029	San Francisco	0.022	Hamburg	0.021	Singapore	0.017	Marseilles	0.020	Melbourne	0.020	Shanghai	0.016	Tanger Med	0.018
19	Callao	0.024	Hampton Roads	0.021	Yokohama	0.021	Portland	0.016	Singapore	0.019	San Francisco	0.018	Houston	0.016	Jeddah	0.017
20	Kobe	0.024	Nagoya	0.018	Nagoya	0.016	Bremerhaven	0.016	Bremen	0.018	Vancouver	0.018	Genoa	0.015	Algeciras	0.017

North America   Europe   East Asia

Figure 4. Top 20 ports in betweenness centrality and their scores estimated from the GDL-1 and GAL-1 models (1969–2016).

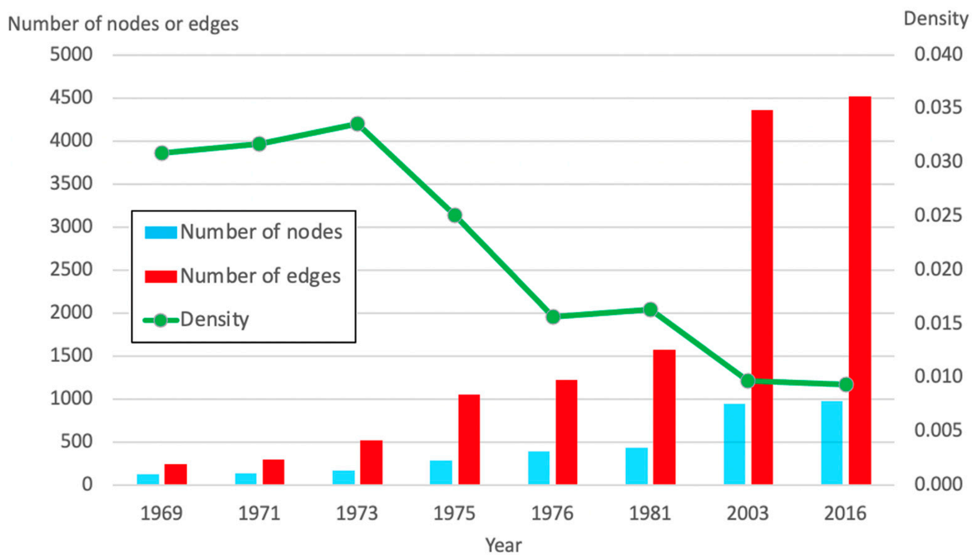


Figure 5. Number of nodes and edges and network density in the GDL-1 model (1969–2016).

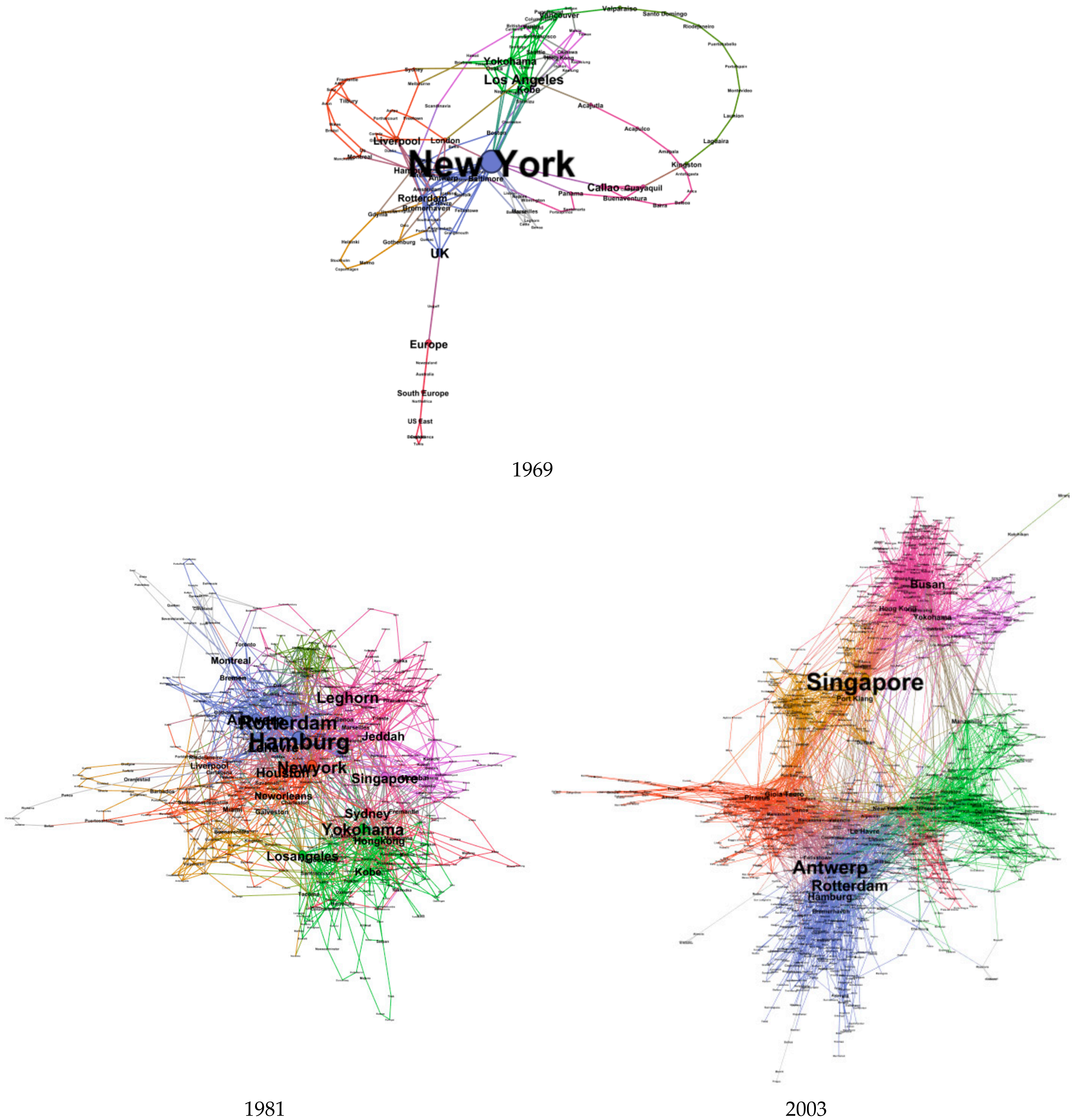


Figure 6. MCS network developed by the GDL-1 model in each year.

The top 20 ports in the betweenness centrality estimated from the GAL-1 model were slightly different from those from the GDL-1 model, as shown in Figure 4; namely, the betweenness centralities of the ports in a specific region were dominant in the GAL-1 model, such as NA in the early 1970s. A possible reason for the difference is that, in the GAL-1 model, almost all ports in high centrality areas were connected to each other and on the shortest path. For some ports, such as Singapore, Port Klang (Malaysia), and Yokohama (Japan), the rank in the GAL-1 model was lower than that in the GDL-1 model, whereas the rank was higher for some ports, such as Rotterdam (the Netherlands), in the GAL-1 model than in the GDL-1 model. This is because the centrality of the last or first ports in the region tends to be larger in the GDL-1 model. In contrast, in hub ports other than the last or first ports in the region, the rank in the GAL-1 model tends to be higher than that in the GDL-1 model.

Table 2 summarizes the number of major communities in the networks of the GDL-1, 2, and 3 models for each time point. Note that the 'major' community is defined as the one that occupies 2% or more of the total number of ports at each time point, considering that the total number of ports at each time point ranges between 100 and 1000. The table indicates that the number of major communities gradually increased until 1981 in a similar manner in each model, but there was a gap among the three models after 2003; the numbers in the GDL-2 model were much larger than those in the GDL-1 and GDL-3 models in 2003 and 2016. This result implies that the GDL-2 model can distinguish between ports connected by trunk routes of global MCS provided by larger vessels with a relatively lower frequency and those connected by feeder transports provided by smaller vessels with relatively higher frequency. For example, the number of communities was often larger in the GDL-2 model in the world major regions, such as the North Sea, Mediterranean Sea, Pacific Ocean, and Indian Ocean, where the trunk route and feeder transport services were mixed.

Table 2. Number of major communities in the GDL-1, 2, and 3 model networks.

	1969	1971	1973	1975	1976	1981	2003	2016
GDL-1	9	9	8	9	9	10	7	8
GDL-2	8	9	9	10	12	12	12	12
GDL-3	7	7	8	10	11	11	8	9

Figure 7 tabulates the top 20 ports in the betweenness centrality with their scores estimated from the GDL-2 and GDL-3 models for each analysis year. The figure implies that the GDL-3 model tends to give a larger betweenness centrality not only for the first or last ports of the regions that feeder ports are less connected with, such as Japanese ports, but also for the tentative attractive ports due to war, such as Saigon (Vietnam) in 1973 and Umm Qasr (Iraq) in 2003. Moreover, we find that compared with these results on the GDL-2 and GDL-3 models, in the GDL-1 model (whose results are shown in Figure 4), regional hub ports that many feeder ports are directly connected with tend to earn larger scores, such as Rotterdam, Hamburg (Germany), Busan (South Korea), and Singapore.

GDL-2 model

	1969		1971		1973		1975		1976		1981		2003		2016	
1	New York	0.424	New York	0.339	New York	0.300	New York	0.181	Singapore	0.137	Rotterdam	0.221	Antwerp	0.174	Antwerp	0.246
2	Los Angeles	0.130	Kobe	0.152	Rotterdam	0.232	Antwerp	0.103	New York	0.132	Apapa	0.162	Singapore	0.139	Singapore	0.208
3	Yokohama	0.105	Shimizu	0.116	Baltimore	0.106	Savannah	0.089	New Orleans	0.104	Leghorn	0.150	Aqaba	0.096	Houston	0.123
4	Callao	0.097	Liverpool	0.112	Tokyo	0.104	Singapore	0.071	Baltimore	0.088	Singapore	0.126	Rotterdam	0.095	Hamburg	0.113
5	Kobe	0.092	Vancouver	0.108	Hong Kong	0.094	Amsterdam	0.069	Port Klang	0.084	Cartagena	0.115	Houston	0.081	Jeddah	0.109
6	Rotterdam	0.078	Baltimore	0.081	Kobe	0.083	New Orleans	0.065	Hamburg	0.082	Cadiz	0.098	Alexandria	0.081	Yokohama	0.081
7	Liverpool	0.072	Balboa	0.080	Vancouver	0.065	London	0.062	Los Angeles	0.065	Lagos	0.092	Fortaleza	0.074	Bilbao	0.068
8	Hamburg	0.069	Rotterdam	0.073	Guayaquil	0.060	Felixstowe	0.054	Kobe	0.063	Sydney	0.087	Umm Qasr	0.072	Bremerhaven	0.067
9	London	0.060	Hampton Roads	0.067	Houston	0.055	Baltimore	0.053	Vancouver	0.059	Antwerp	0.078	Busan	0.071	Rotterdam	0.064
10	Vancouver	0.059	Portland	0.060	Liverpool	0.050	Copenhagen	0.052	Brisbane	0.054	New York	0.077	Kobe	0.060	Alexandria	0.063
11	Guayaquil	0.059	Rio de Janeiro	0.056	Hampton Roads	0.046	Vancouver	0.048	Dunkirk	0.053	Le Havre	0.073	Bilbao	0.060	Busan	0.060
12	Bremerhaven	0.058	Tokyo	0.056	Gothenburg	0.041	Philadelphia	0.048	Barcelona	0.050	Hamburg	0.072	Karachi	0.050	New Orleans	0.059
13	Baltimore	0.050	Callao	0.054	Rio de Janeiro	0.039	Manchester	0.046	Liverpool	0.046	Houston	0.071	Hamburg	0.043	Altamira	0.049
14	Kingston	0.046	Montreal	0.051	Montreal	0.038	Galveston	0.044	Callao	0.043	Piraeus	0.070	Manaus	0.042	Kobe	0.046
15	Valparaiso	0.046	Los Angeles	0.044	Savannah	0.035	Fremantle	0.041	Wellington	0.043	Montreal	0.058	Lae	0.041	Genoa	0.045
16	Buenaventura	0.041	San Francisco	0.041	Le Havre	0.035	Norfolk	0.040	Rotterdam	0.043	Baltimore	0.057	Jeddah	0.039	Kristiansand	0.043
17	Acajutla	0.041	Yokohama	0.040	Galveston	0.030	Charleston	0.039	Le Havre	0.040	Bilbao	0.056	Leghorn	0.035	Durban	0.042
18	Panama	0.040	Seattle	0.040	Balboa	0.030	Gothenburg	0.038	Savannah	0.038	Honolulu	0.053	Port Klang	0.035	Baltimore	0.041
19	Antwerp	0.039	Osaka	0.039	Manila	0.029	Conakry	0.037	Yokohama	0.037	Los Angeles	0.051	Casablanca	0.033	Immingham	0.039
20	Laguaira	0.034	Salvador	0.038	Genoa	0.027	Rotterdam	0.037	Portland	0.037	Vancouver	0.051	Hodeidah	0.032	Shanghai	0.032

GDL-3 model

	1969		1971		1973		1975		1976		1981		2003		2016	
1	New York	0.394	Kobe	0.179	New York	0.342	New York	0.174	Yokohama	0.195	Rotterdam	0.248	Umm Qasr	0.195	Antwerp	0.196
2	Callao	0.126	New York	0.157	Rotterdam	0.164	Glasgow	0.095	New York	0.180	Leghorn	0.190	Rotterdam	0.188	Houston	0.139
3	Los Angeles	0.118	Portland	0.138	Hong Kong	0.144	New Orleans	0.092	Rotterdam	0.154	Cartagena	0.154	Kobe	0.186	Yokohama	0.133
4	Yokohama	0.104	Shimizu	0.121	Baltimore	0.135	Copenhagen	0.090	Port Klang	0.147	Bilbao	0.153	Yokohama	0.158	Singapore	0.128
5	Kobe	0.095	Baltimore	0.108	Guayaquil	0.098	Baltimore	0.082	Singapore	0.120	Buenaventura	0.133	Antwerp	0.152	Alexandria	0.125
6	Rotterdam	0.074	Moji	0.094	Tokyo	0.092	Hong Kong	0.079	Nakhodka	0.108	Antwerp	0.131	Vladivostok	0.141	Benghazi	0.120
7	Baltimore	0.064	Tacoma	0.069	Houston	0.088	Philadelphia	0.074	Kobe	0.103	Lagos	0.115	Singapore	0.103	Rotterdam	0.115
8	Bremerhaven	0.060	Houston	0.066	Vancouver	0.077	Antwerp	0.068	Nagoya	0.102	Cadiz	0.100	Trondheim	0.100	Hamburg	0.115
9	Guayaquil	0.056	Seattle	0.063	Miami	0.070	Gothenburg	0.063	Piraeus	0.098	Apapa	0.099	Aqaba	0.090	Bilbao	0.111
10	Vancouver	0.056	Puget Sound	0.061	Savannah	0.053	Houston	0.053	Haifa	0.095	Singapore	0.099	Bilbao	0.083	Kobe	0.108
11	Buenaventura	0.053	Liverpool	0.057	Algiers	0.051	Apapa	0.051	Portland	0.087	Bremerhaven	0.096	Genoa	0.079	Incheon	0.102
12	Liverpool	0.045	Rotterdam	0.048	Yokohama	0.050	Fremantle	0.050	Osaka	0.087	Matarani	0.095	Houston	0.075	Immingham	0.099
13	Kingston	0.044	San Francisco	0.042	Saigon	0.047	Conakry	0.048	Oakland	0.074	New Orleans	0.095	Busan	0.074	Kristiansand	0.089
14	Valparaiso	0.043	Hamburg	0.039	Kobe	0.047	London	0.045	New Orleans	0.074	Sheerness	0.086	Tripoli	0.057	Genoa	0.080
15	Acajutla	0.039	Southampton	0.031	Manila	0.046	Hamburg	0.044	Los Angeles	0.073	Houston	0.082	Hull	0.053	Fremantle	0.069
16	Osaka	0.037	Brisbane	0.027	Cadiz	0.043	Savannah	0.043	Santo Domingo	0.064	Galveston	0.074	Hodeidah	0.052	Osaka	0.068
17	Gothenburg	0.036	Callao	0.022	Los Angeles	0.043	Amsterdam	0.041	Liverpool	0.062	Los Angeles	0.073	Incheon	0.048	Flying Fish Cove	0.068
18	Hamburg	0.035	Wilmington	0.022	Montreal	0.041	Newport News	0.039	Seattle	0.050	Matadi	0.063	Alexandria	0.047	Busan	0.066
19	Antwerp	0.034	Antwerp	0.020	Buenaventura	0.039	Tokyo	0.036	Sheerness	0.049	New York	0.063	Kingston	0.039	Las Palmas	0.063
20	Laguaira	0.032	Vancouver	0.020	Lisbon	0.037	Hampton Roads	0.036	Halifax	0.048	Hamburg	0.061	Jakarta	0.038	Casablanca	0.061

North America | Europe | East Asia

Figure 7. Top 20 ports in betweenness centrality and their scores estimated from the GDL-2 and GDL-3 models (1969–2016).

5. Structural Changes in the Emergence of MCS (1969–1981)

We then focus on the period from 1969 to 1981 and changes in the MCS network from a medium-term perspective in the era of the emergence of global MCS. Figure 8 summarizes the number of container ports where at least one LS was connected from 1969 to 1976 for each region of the world, and Figure 9 shows the MCS networks developed by the GDL-1 model in 1971, 1973, 1975, and 1976.

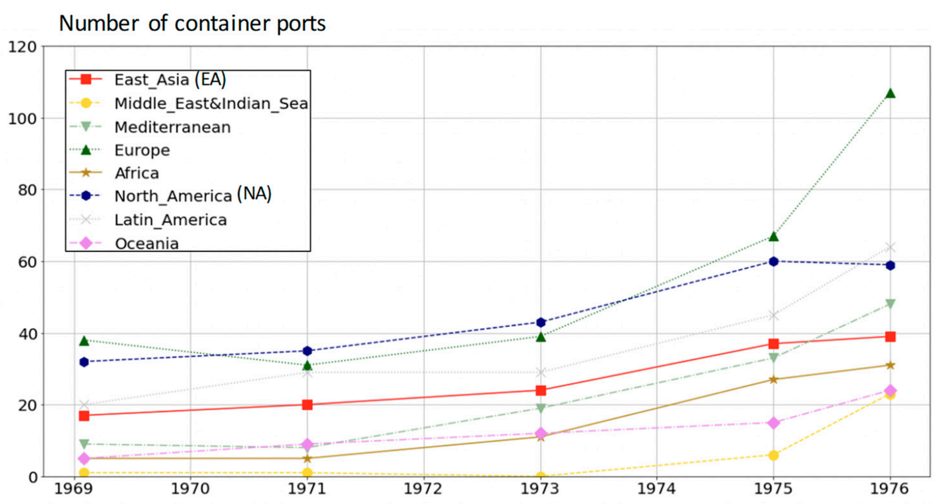


Figure 8. Number of container ports in each region of the world (1969–1976).

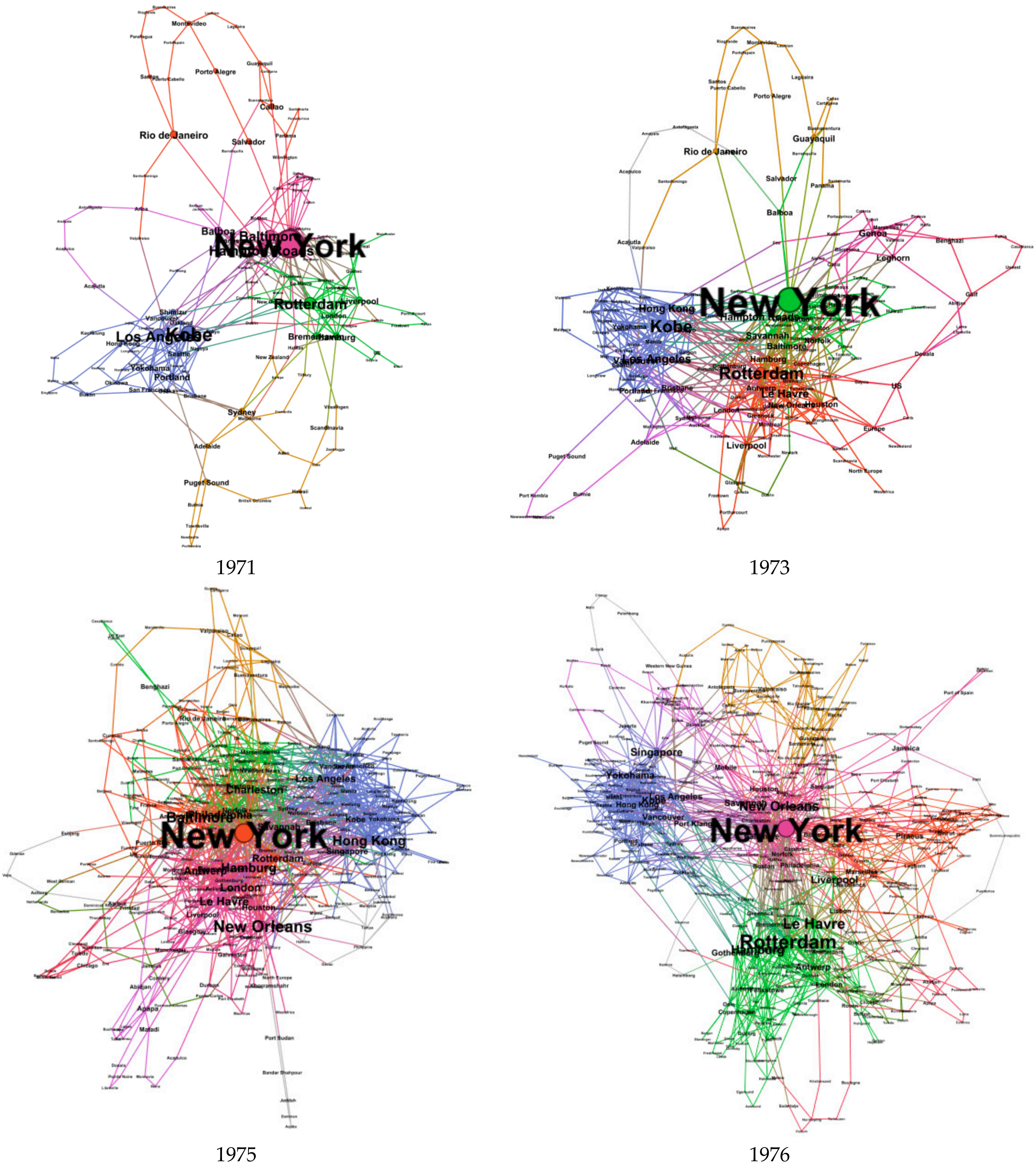


Figure 9. MCS network developed by the GDL-1 model in each year of the 1970s.

First, Figure 8 indicates that the number of container ports significantly increased in the middle of 1970s, even in regions outside of the three major regions, such as Latin America and the Middle East. This implies that container shipping rapidly expanded worldwide. In contrast, as indicated in Figure 5 in the previous section, after the network density slightly increased from 1969 to 1973, it dropped until 1976. The port rankings estimated from the GDL-1 model shown in Figure 4 also indicate the trend that the betweenness centrality rankings of NA ports had been high from 1969 to 1975 and then gradually declined since 1976, whereas those of European and EA ports rose. As a result, in 1981, as mentioned in the previous section, the structure of the network changed to multipolar. Figures 6 and 9 indicate that the unipolar network centering on the port of NY had gradually changed to a multipolar structure from 1969 to 1981. Moreover, as shown in Figure 4, European ports took the lead in 1981, and the difference in the average betweenness centrality of major ports between the three major regions was also reduced.

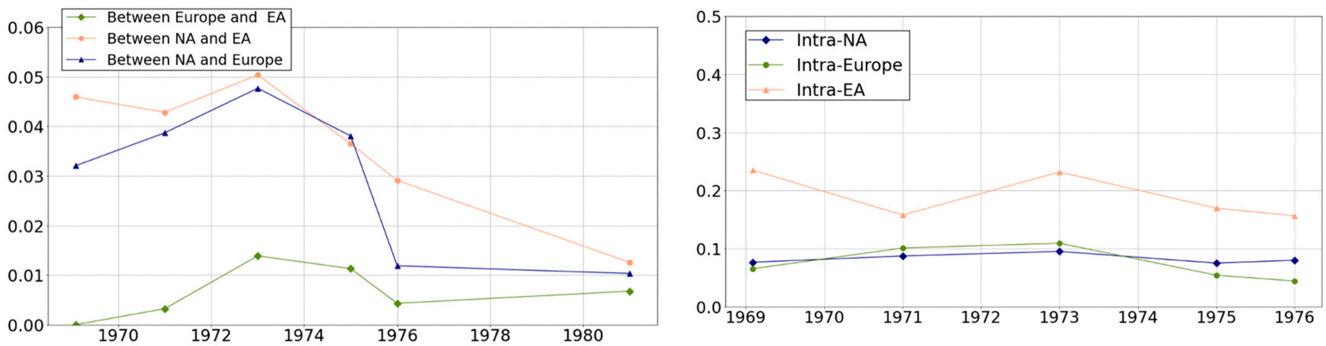
This observation, based on the GDL-1 model, that the NA-centered network structure in 1969 gradually changed to a multipolar structure with three major regions until 1981, is also obtained through the analyses of the network developed by the GAL models. As shown in Figure 4, NA ports were dominant in the betweenness centrality from 1969 to 1975; however, they competed with European ports in 1976 and lost their competitiveness rapidly during and after 1981. Regarding this point, the NYK report (1981) [30] stated that 'the trunk routes of LSs, which connected major regions in the world, were converted from conventional vessels into containerships until the early 1970s, and then the feeder services began to expand from the middle of the 1970s (note that was originally written in Japanese and translated into English by the authors).' Therefore, we conclude that the replacement of conventional LSs with containerships caused diversification of the MCS network in trunk routes, resulting in a reduction in the betweenness centralities of major ports. Moreover, since then, the expansion of the feeder services, which connected new container ports in the developing regions to major ports, enhanced the increase in the number of ports in developing regions.

6. Impact of Reopening of the SC in 1975

Following the outbreak of the third Arab–Israeli War in the Middle East in 1967, the SC was blocked for about 8 years. During the blockade, maritime shipping between Europe and Asia was forced to make a long voyage via the Cape of Good Hope at the southernmost point of the African continent. This situation was resolved after minesweeping operations by the U.S. Army in mid-1975 after the fourth Arab–Israeli War (Yom Kippur War). The reopening of the SC greatly reduced the distance of maritime shipping between Europe and EA. In this section, we discuss the impact of the SC reopening on the global MCS network. Note that it is difficult to compare the networks before and after the SC blockade because there was no global MCS network before 1967.

First, Figure 9 indicates that no significant changes were identified in the GDL-1 model networks in 1975 and 1976. We then focus on the differences in the inter- and intra-regional densities. Figure 10 depicts the changes in inter- and intra-regional densities of the three major regions in the GDL-1 model network from 1969 to 1981. Inter-regional density focuses only on the edges connecting two different regions, whereas intra-regional density focuses only on the edges within a region. Note that intra-regional densities in 1981 are not included in the figure because the data after 1981 did not contain information on intra-regional LSs, as described in Section 3.1. As indicated in Figure 10, all the inter-regional densities (including those between Europe and EA) dropped sharply in 1976, whereas all the intra-regional densities did not change significantly from 1975 to 1976.

Subsequently, we apply the GAL model in the following analyses. For the following analyses, we classify each port into several regional groups, as shown in Figure 11, which may share similar impacts of the reopening of the SC related to their location and size based on Shibasaki et al. (2016) [31] and Shibasaki et al. (2017) [32]. Figure 12 summarizes the average number of ports connected to three representative ports in each region's group in the GAL-1 model. As shown in Figure 12, the number of connected ports on both sides of the SC (i.e., group 1: smaller ports in the Mediterranean Sea near the SC; group 4: Red Sea/Indian Ocean ports) increased significantly from 1975 to 1976. This discontinuous change from 1975 to 1976 may have been related to the reopening of the SC.



Inter-regional densities   Intra-regional densities (until 1976)

Figure 10. Inter-regional and intra-regional densities of major regions in the GDL-1 model network (1969–1981).

Figure 11. Classification of port groups of the world with representative ports.

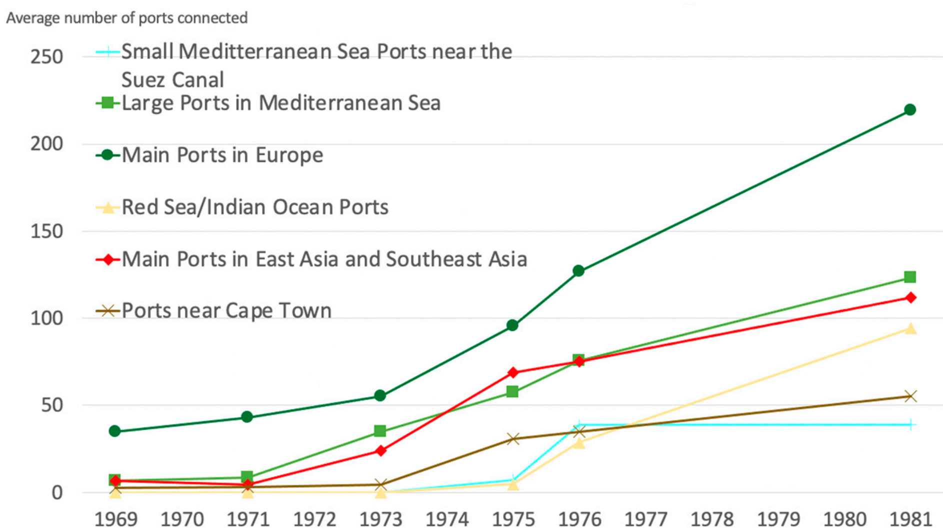


Figure 12. Average number of ports connected for each regional group.

For further understanding of the influences of the closure of the SC, we focus on three ports at the sphere of the SC: Jeddah (Saudi Arabia), Dubai (United Arab Emirates), and Alexandria (Egypt). Figure 13 indicates the results in each GAL model in the port of Jeddah as an example of the group 4 port. Although an increase in number was observed in 1976 in the GAL-1 model, it was mainly caused by the increase in intra-regional connections, not connections with the ports at the other end of the SC. Moreover, the results for the GAL-2 and GAL-3 models reveal that the weighted numbers of connected ports in 1975 and 1976 were much smaller, indicating that both the frequency and annual capacity of the LSs called at Jeddah were very low at those times. In contrast, not only did the number of ports connected by the LSs significantly increase in 1981, including connections with European and EA ports, but the frequency of the LSs and the size of the vessels also increased significantly. The same observation was found in the port of Dubai, as indicated in Figure 14. In the GAL-1 model, the port of Dubai was connected to several NA ports via the SC in 1976; however, the weighted numbers of ports connected to them in the GAL-2 and GAL-3 models were very low. Similarly, regarding the ports in group 1, as indicated in Figure 15, as an example of the GAL-1 model in the port of Alexandria, the number of connections increased in 1976; however, it was mostly derived from connections with European ports, not new connections with eastern ports across the SC. Therefore, it cannot be said that the reopening of the SC increased the number of connected ports immediately.

The above analysis does not explain the discontinuous change from 1975 to 1976 in the density of inter-regional connections in Figure 10. Thus, we then summarize the changes in the average number of ports of call per service from 1969 to 1981 in Figure 16 for the inter-regional LSs between the three major regions and the intra-regional LSs in each major region. These numbers are also calculated from the same source acquired from the NYK reports, although the numbers for intra-regional LSs in 1981 are not displayed because of comparability, similar to other figures. The figure indicates that the average number of ports of call per service in all inter-regional LSs sharply increased in 1976 and decreased again in 1981. Among them, the rapid increase in 1976 in the LSs between Europe and EA was caused by an increase in the number of ports of call in Europe and EA, not in the Middle East and South Asia, which are located in the middle of this trunk route, because the container ports in these regions were underdeveloped at that time. The inter-regional density in the GDL-1 model, therefore, declined in 1976 because the increase in the number of ports of call in the inter-regional LSs geographically limited the first and last ports of these regions to some specific ports, such as Antwerp and Singapore.

According to the NYK report (1976) [33], the global MCS market in 1975 faced a surplus of containerships because of the reduction in shipping time caused by the reopening of the SC. Moreover, the NYK report (1976) [33] stated that the number of transported containers in 1975 declined by at least about 20% due to the prolonged recession since 1974 and that LSs operated by Maersk increased the number of ports of call per service. In summary, the increase in the average number of ports of call in the inter-regional LSs (including those between Europe and EA) in 1976 was considered to be a result of the reorganization of LS networks to cope with the decrease in the loading factor of containerships, which was reciprocally caused by the decrease in cargo shipping demand due to the global recession since the first oil shock and the surplus of containerships due to the reopening of the SC. Note that both the first oil shock and the reopening of the SC were consequences of the same event, the Arab–Israeli War.

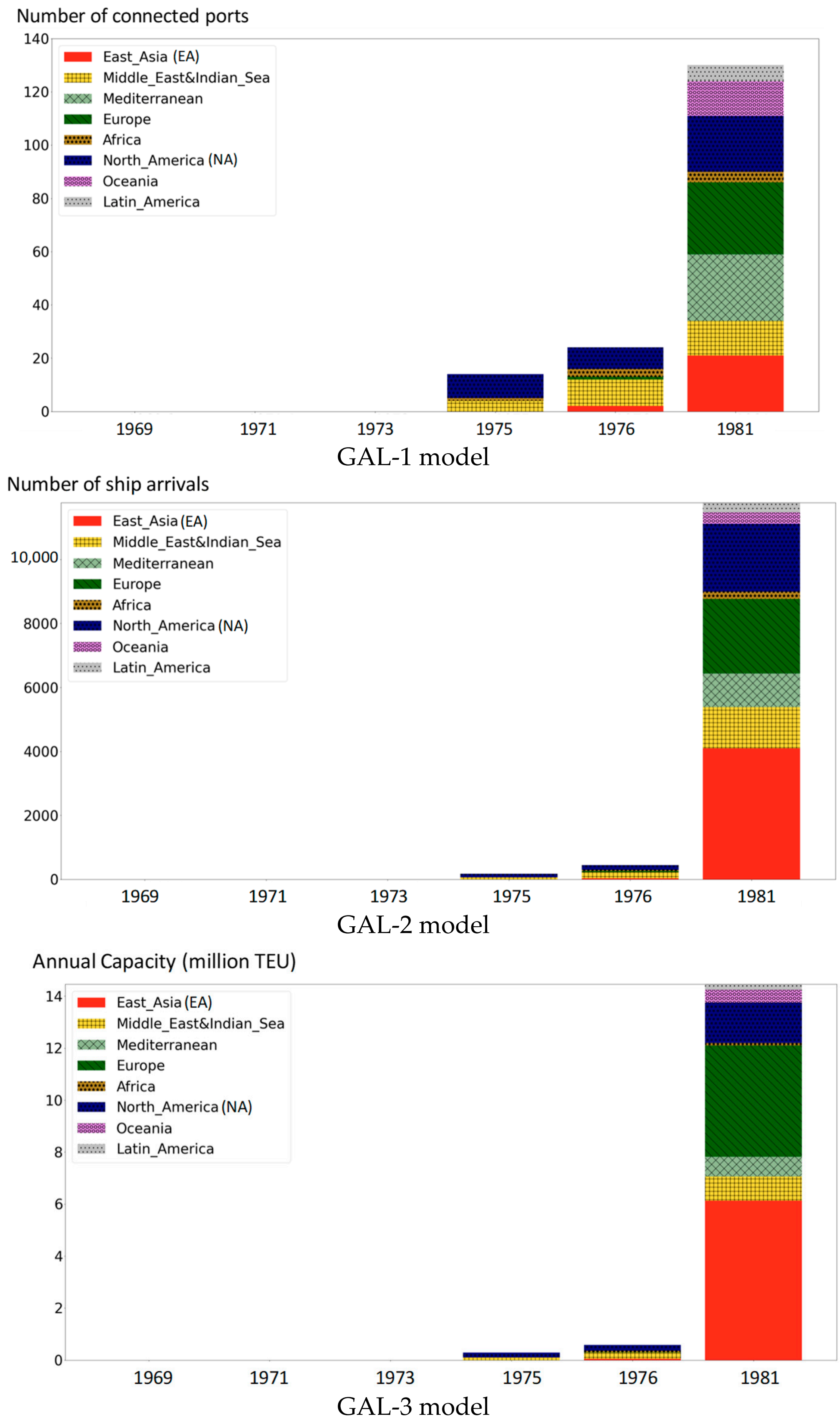


Figure 13. (Weighted) number of connected ports and regional breakdown in the port of Jeddah (1969–1981).

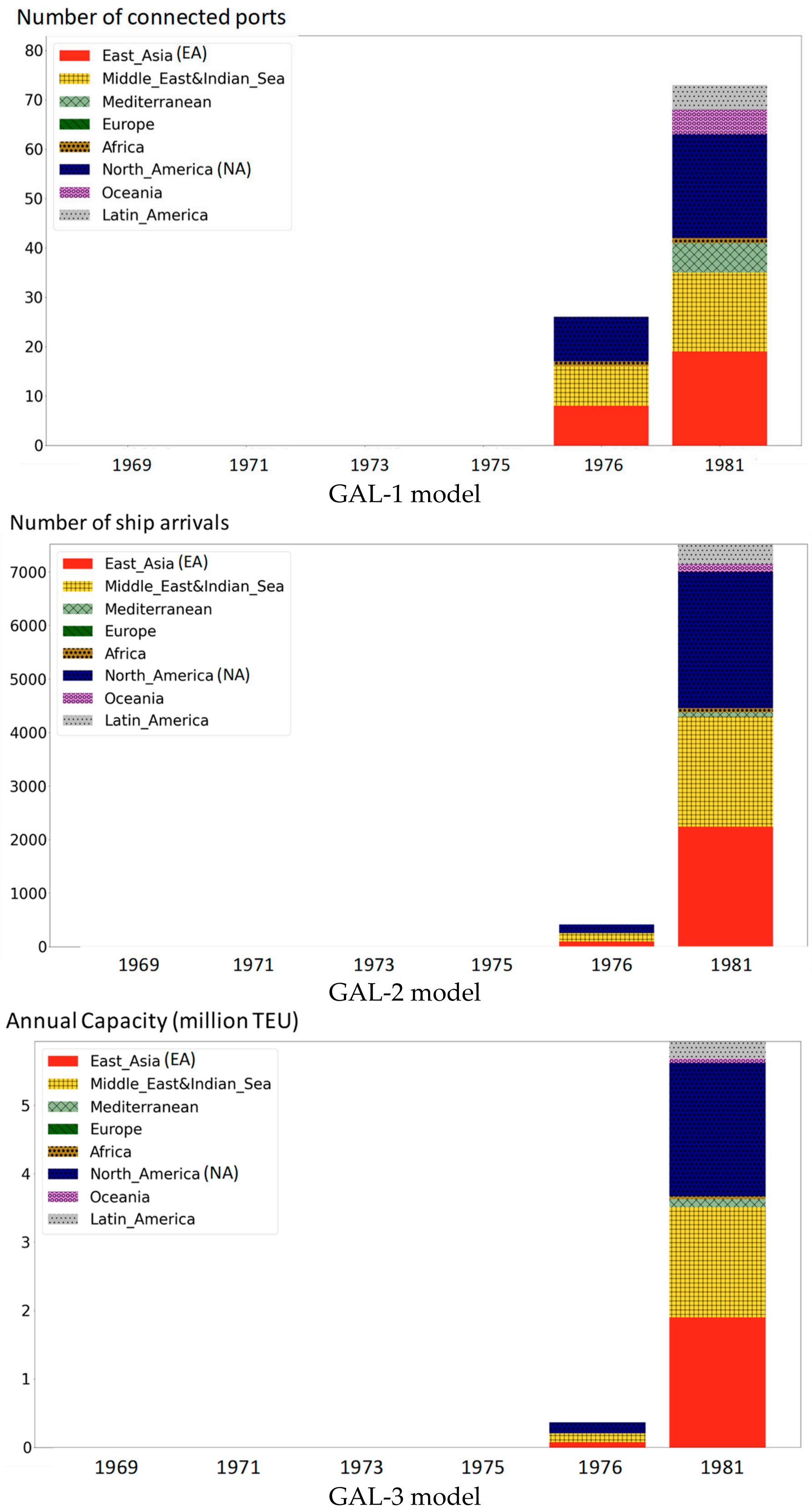


Figure 14. (Weighted) number of connected ports and regional breakdown in the port of Dubai (1969–1981).

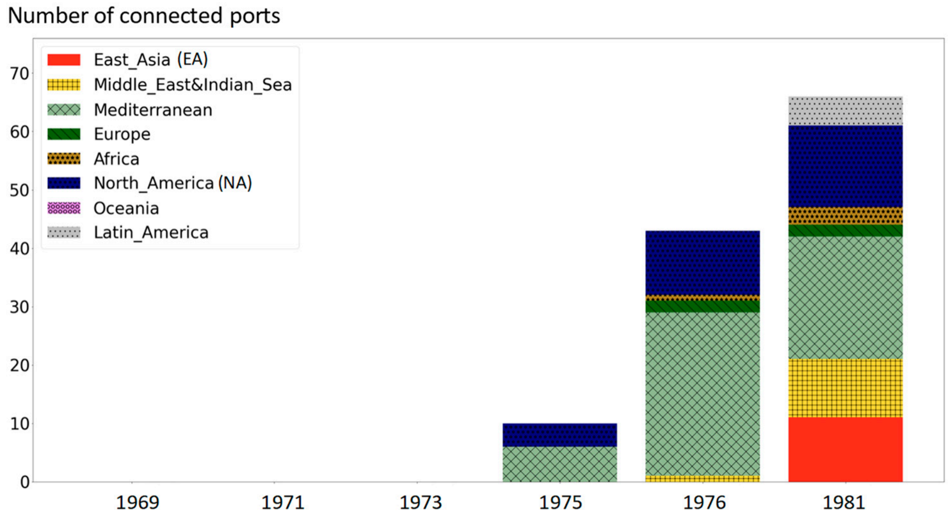


Figure 15. Number of connected ports and regional breakdown in the port of Alexandria (GAL-1 model, 1969–1981).

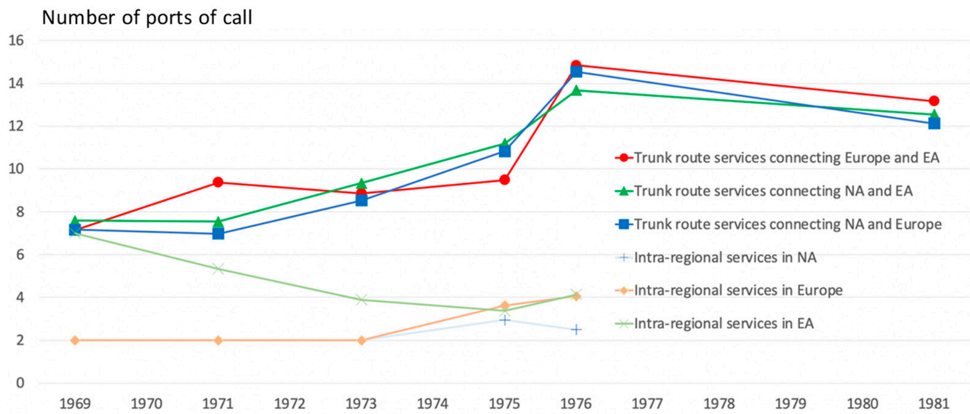


Figure 16. Average number of ports of call per service (1969–1981).

7. Conclusions

Using the global LS network data mainly provided by NYK, this study applied a network analysis method based on graph theory to the global MCS network, mainly in the 1970s. This study obtained a long-term overview that the network centered on NA, in the era of the emergence of MCS, had become multipolar by the 1980s and finally changed to a hub-and-spoke structure. Moreover, the importance of each port in the hub-and-spoke network was confirmed, and more elaborate and detailed clusters were detected using several models in which the method of edge construction and the consideration of frequency and capacity of each service are different.

Subsequently, through analyses focusing on the 1970s, changes in the MCS network were observed. These included the replacement of conventional LSs with MCS in trunk routes in the early 1970s and the development of the feeder transport network and the networks in the peripheral regions since the middle of the 1970s. There had been a relative increase in the number of ports in peripheral regions in the middle of the 1970s. These findings correspond with the descriptions in the NYK reports and Rua [34].

Moreover, detailed analyses focusing on the reopening of the SC in 1975 revealed discontinuous changes in inter-regional density from 1975 to 1976. Through both quantitative and qualitative discussions, it was found that the recession caused by the first oil crisis in 1973 decreased the MCS demand, whereas the reopening of the SC caused a surplus of containerships. Therefore, the number of ports of call increased, especially for the inter-regional LSs, which caused them to geographically limit the first and last ports in each region to some specific ports, resulting in a decrease in inter-regional density. In conclusion, we can say that the reopening of the SC and the first oil crisis indirectly affected the global MCS network through the surplus of vessels rather than directly affecting it in a geographical sense.

We believe that this study contributes to accumulating the methodology and empirical knowledge on the vulnerability analysis of the present and future MCS networks, including the impact of shortcutting the shipping route for containership supplies. We used two different models (GDL and GAL) in terms of edge construction with three different types of edge weights according to the objective of the analysis and conducted a detailed analysis focusing on port characteristics in each region. The GDL is more suitable for the analysis of the movement network of containerships such as the first and last ports of call in the region and the shape of the networks through visualization, whereas the GAL is suitable for the analysis of hub-and-spoke structures with transshipments but not suitable for the visualization analysis because the density of the network is too high. Moreover, we confirmed the necessity of considering the indirect effects (such as economic downturn) of a wide range of events in the same era when analyzing the effects on the MCS network. This implication that the indirect effects should be sufficiently considered would be useful in predicting not only the effects when the SC is closed for a much longer period than the closure in 2021, but also the impacts of other types of current crises on network vulnerability for MCS, such as the heavy port congestion observed in the latter half of 2021 in the United States and the invasion of Ukraine by Russia.

However, owing to poor data accuracy, we were unable to analyze the MCS networks at shorter time intervals in the latter half of the 1970s and in the 1980s, in which a hub-and-spoke structure was formed. Therefore, more detailed and multifaceted analyses using more comprehensive data on longer time scales (for example, by digitizing Lloyd's data) should be conducted. The use of physical distance as the weight of the edges is also a further challenge, which is difficult to acquire exhaustively for all combinations of ports.

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Review

Uncertainties in Liner Shipping and Ship Schedule Recovery: A State-of-the-Art Review

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Abstract: Each shipping line is expected to establish a reliable operating model, and the design of ship schedules is a key operational consideration. Long-term profits for shipping lines can be expected from a well-designed ship schedule. In today's liner service design, managing the time factor is critical. Shipping schedules are prone to different unexpected disruptions. Such disruptions would necessitate a near-real-time analysis of port capacity and re-design of the original ship schedule to offset the negative externalities. Ship schedule recovery strategies should be implemented to mitigate the effects caused by disruptions at ports or at sea, which may include, but are not limited to, ship sailing speed adjustment, handling rate adjustment at ports, port skipping, and port skipping with container diversion. A proper selection of ship schedule recovery strategies is expected to minimize deviations from the original ship schedule and reduce delays in the delivery of cargoes to the destination ports. This article offers a thorough review of the current liner shipping research primarily focusing on two major themes: (1) uncertainties in liner shipping operations; and (2) ship schedule recovery in response to disruptive events. On the basis of a detailed review of the available literature, the obtained results are carefully investigated, and limitations in the current state-of-the-art are determined for every group of studies. Furthermore, representative mathematical models are provided that could be further used in future research efforts dealing with uncertainties in liner shipping and ship schedule recovery. Last but not least, a few prospective research avenues are suggested for further investigation.

Keywords: liner shipping; uncertainties; ship schedules; schedule recovery; recovery strategies; literature survey

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1. Introduction

1.1. Background

Maritime transport outperforms other transportation modes in terms of the amount of transported cargoes measured in ton-kilometers. The proportion of cargo moved by sea varies from year to year, but in the recent years, waterborne trade in the United States (USA) has represented between 22 and 24 percent of the total ton-kilometer cargo movements, which is more than $1.5 trillion worth of goods [1]. Overall, this results in a yearly economic output of $5.4 trillion. The maritime transportation system plays an important role in Europe as well. According to the European Commission, waterborne trade between nations (also known as short-sea shipping) accounts for nearly 41 percent of the freight transport market in Europe [1]. Due to the lower cost of maritime transport in comparison to other modes of shipping, such as air freight, international seaborne trade has increased by 67 percent in terms of weight between 1980 and 2007 [2]. Moreover, the international waterborne trade volumes have been constantly growing since 2009 and reached approximately 11.0 billion tons in 2018, which is more than a 40% increase compared to 2009 (see Figure 1). Nevertheless, in comparison to other modes of transportation, the sea freight industry is facing unprecedented and chaotic conditions, such as port congestion, labor strikes, severe weather conditions, shipping container shortages, and customs delays [3–6]. After the analysis of 5410 ship arrivals at ports, Drewry Shipping determined that approximately 21% of ships were one day behind the planned arrival, whereas 22% of ships were delayed by two or more days [7].

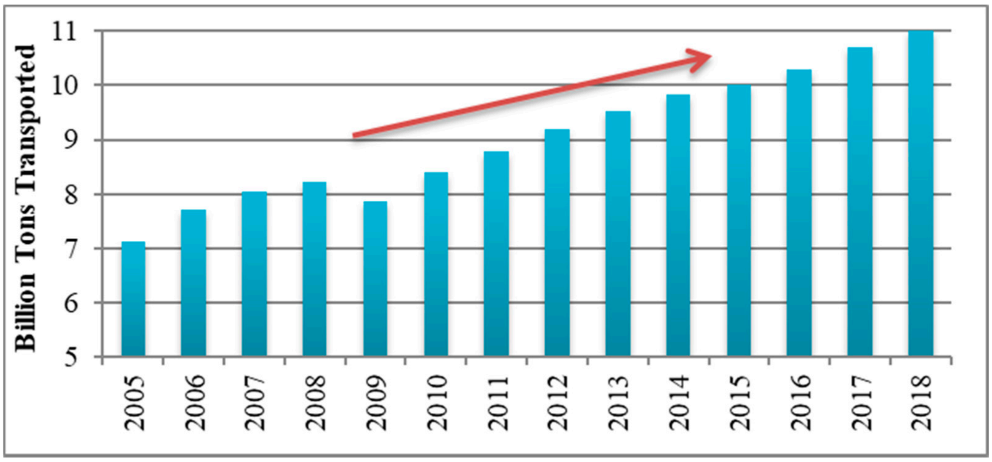


Figure 1. International waterborne trade volumes between 2005 and 2018.

Weather can have a critical impact on ships carrying cargo. Given that transport is an inherently logistical industry relying on the surrounding physical infrastructure, it is constantly exposed to the whims of the natural environment. While most cargo ships can withstand extreme inclement weather conditions, strong tropical cyclones (e.g., hurricanes, typhoons) can make sailing and port operations too dangerous. Adverse weather conditions may cause significant delays in ship arrivals at ports and result in substantial monetary losses. As an example, about USD 12 billion worth of damage was incurred to the Japanese maritime infrastructure during the 2011 Tohoku tsunami on Japan's Pacific Coast [8]. The Ports of Felixstowe and Southampton, which are considered some of the largest container ports in the United Kingdom, experienced severe ship service disruptions as a result of strong winds in January 2012 [9]. The Port of New York/New Jersey was shut down for one week in November 2012 due to Hurricane Sandy. The 2019 North Atlantic hurricane season recorded a total of 18 named storms, 6 hurricanes, and 3 major hurricanes [10]. As a result of extreme weather events, the reliability of transpacific and transatlantic schedules fell below 40% in 2019. Furthermore, the container terminals in Baton Rouge (LA, USA) were completely shut down due to severe tropical storms in August 2020 [8].

As underlined by Notteboom [11], significant delays in liner shipping operations could be endured due to maritime passage, port access, and marine terminal operations. Channels play an important role in liner shipping operations, as they enable the passage of ships to the designated locations. However, many channels impose limitations on the ship size and may incur additional waiting time (especially, if certain ships do not follow the previously negotiated arrival time). Certain ports around the world are subject to the tidal effect, when the depth of access channels fluctuates throughout the day [12,13]. Oversized ships have to wait during particular time periods to ensure that the depth of the access channel will be safe to navigate. Safe ship navigation is critical, as navigational issues may disrupt channel operations and cause substantial delays (e.g., the 6-day Suez Canal obstruction caused by the large 20000-TEU ship "Ever Given" in 2021).

Considering increasing trade volumes and the existing terminal capacity constraints, the berth availability and handling equipment may not be always guaranteed, especially when the previously negotiated arrival time windows have been missed by the approaching ships. Ships that arrive outside the agreed time windows significantly disrupt marine terminal operations and cause port congestion. Labor strikes could be another reason for delays in container handling at marine terminals or even complete terminal shutdowns. As an example, a total of ten marine container terminals were shut down at the Ports of Los Angeles and Long Beach (USA) in November 2012 due to labor strikes [9]. The container traffic at both ports experienced a standstill. Equipment failures at marine container terminals are considered a rare event, but they do occur from time to time. The quay crane failure at the DP World Port Botany terminal (Sydney, Australia) caused a sudden disruption and unexpected slot cancellations in September 2013 [9].

The outbreak of COVID-19 is recognized as a major disruptive event for liner shipping and maritime transportation [14–17]. As a result of the global economic crisis that was caused by the COVID-19 pandemic, the international maritime trade volumes reduced by 4.1% in 2020 [14]. Marine terminal operators experienced significant challenges imposed by the pandemic. In particular, certain terminal operators had to shut down their terminals and quarantine their employees due to the fact that some of the employees tested positive for the virus [17]. The closure of marine terminals caused substantial supply chain disruptions. The ships loaded with import goods were queued in the vicinity of marine terminals but could not be served due to the terminal closures. Ship operations were subjected to national and municipal restrictions, which frequently resulted in port clearance delays [18]. Additional restrictions were imposed for the personnel embarking and disembarking, cargo loading and discharge, and ship refueling. Tensions in international trade resulted in trade pattern shifts and a search for alternative markets (e.g., a decrease in trade flows from China and a transition to other markets—[14]). The USA increased the exports of its merchandise to other countries, which assisted with the compensation for the decrease in exports from China.

1.2. Existing Research Gaps and Contributions of This Study

A large number of the existing research efforts were dedicated to the planning of different liner shipping operations, including fleet deployment [19–23], port service frequency determination [24–27], ship sailing speed optimization [28–31], and ship schedule design [32–41]. However, the existing research efforts generally do not account for potential uncertainties in liner shipping operations and do not model any recovery options that could be used to effectively respond to disruptions. Furthermore, a number of survey studies were conducted in the past aiming to provide a holistic overview of the liner shipping literature [42–48]. Nevertheless, there is still a lack of systematic literature surveys that specifically concentrate on uncertainties in liner shipping operations and ship schedule recovery. Considering the increase in the occurrence of disruptive events and their negative impacts on liner shipping operations, the present study aims to offer the following contributions to the state-of-the-art:

- ✓ A comprehensive up-to-date review of the liner shipping literature is conducted with a specific emphasis on uncertainties in liner shipping operations and ship schedule recovery.
- ✓ The collected studies are reviewed in a systematic way, capturing the main assumptions regarding sailing speed and port time modeling, objective(s) considered, key components of objective functions(s) considered, uncertain elements modeled, ship schedule recovery options modeled, solution approaches adopted, and certain specific considerations adopted.
- ✓ A representative mathematical formulation is presented for the ship scheduling problem with uncertainties, which can be used by shipping lines to assess the impacts of uncertainties on liner shipping operations and design robust ship schedules. Moreover, the proposed mathematical formulation can serve as a foundation for future efforts that concentrate on uncertainties in liner shipping operations.
- ✓ A set of representative mathematical formulations are presented for the ship schedule recovery problem with various recovery options (i.e., sailing speed adjustment,

handling rate adjustment, port skipping, and port skipping with container diversion), which can be used by shipping lines to select the appropriate ship schedule recovery option(s). Furthermore, the proposed mathematical formulations can serve as a foundation for future efforts that concentrate on ship schedule recovery.

✓ Research gaps in previous and contemporary studies on uncertainties in liner shipping operations and ship schedule recovery are clearly identified, and future research areas that should be considered in the following years are specifically underlined.

The outcomes from this research are expected to assist the relevant stakeholders involved in liner shipping operations with improvements in the reliability of their schedules and selection of the appropriate recovery options in response to major disruptive events. Reliable ship schedules and appropriate recovery options will further decrease cargo delivery delays, improve customer service, and enhance the overall sustainability of maritime transport. The next sections of the manuscript contain the following information. Section 2 provides a detailed description of how the literature search was performed, aiming to capture the most relevant studies on uncertainties in liner shipping operations and ship schedule recovery. Section 3 presents a detailed description of the ship scheduling problem with uncertainties, a formulation of the supporting mathematical model, a review of the relevant studies, a literature summary, and future research needs in the area of uncertainties in liner shipping operations. After that, Section 4 presents a detailed description of the ship schedule recovery problem, formulations of the supporting mathematical models, a review of the relevant studies, a literature summary, and future research needs in the area of ship schedule recovery. The main study conclusions are provided in Section 5.

2. Literature Search

A thorough literature search is essential in order to perform a comprehensive survey study. As a part of this research effort, a detailed literature search was conducted by means of the content analysis method [49]. The following keywords and their combinations were used to guide the search process: "liner shipping", "shipping lines", "liner shipping companies", "ship schedule design", "vessel schedule design", "ship timetable design", "vessel timetable design", "uncertainties", "ship schedule recovery", "vessel schedule recovery", "recovery strategies", and "recovery options". The following search engines were used during the search process: Science Direct, IEEE Explore, Web of Science, Scopus, Springer Link, and Google Scholar. Hundreds of studies were identified after the initial search. Books, book chapters, journal papers, and conference papers written in English were considered. After a review of the collected studies, it was found that a total of 43 studies were closely related to the theme of the present literature survey, directly focusing on uncertainties in liner shipping operations and ship schedule recovery. Figure 2 depicts the distribution of selected studies by subject category and year of publication, whereas Figure 3 depicts the distribution of collected studies by publisher.

It can be observed that the total number of research studies on uncertainties in liner shipping operations and ship schedule recovery comprised 25 and 18, respectively. Both study groups started receiving more and more attention from the scientific community after the year 2015. Such a pattern can be justified by an increase in the number of disruptive occurrences in liner shipping operations and the urgent need for effective ship schedule recovery strategies. It was found that the collected studies were produced by a variety of different publishers, including Elsevier, Springer, IEEE, INFORMS, TRB, MDPI, and Taylor & Francis. Elsevier and Springer produced the majority of studies on uncertainties in liner shipping operations and ship schedule recovery with a total of 21 and 8 studies, respectively. IEEE and INFORMS published a total of five and three relevant studies, respectively. Furthermore, TRB, MDPI, and Taylor & Francis each published two papers. As a result of the conducted analysis, it was found that the majority of studies were published in Transportation Research Part E: Logistics and Transportation Review (with a total of six studies) and European Journal of Operational Research (with a total of four studies).

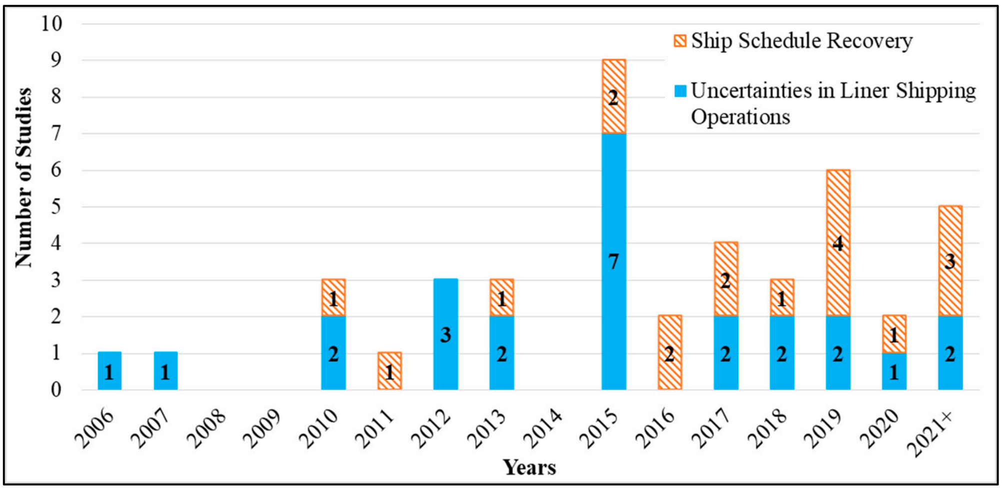


Figure 2. Distribution of the collected studies by year.

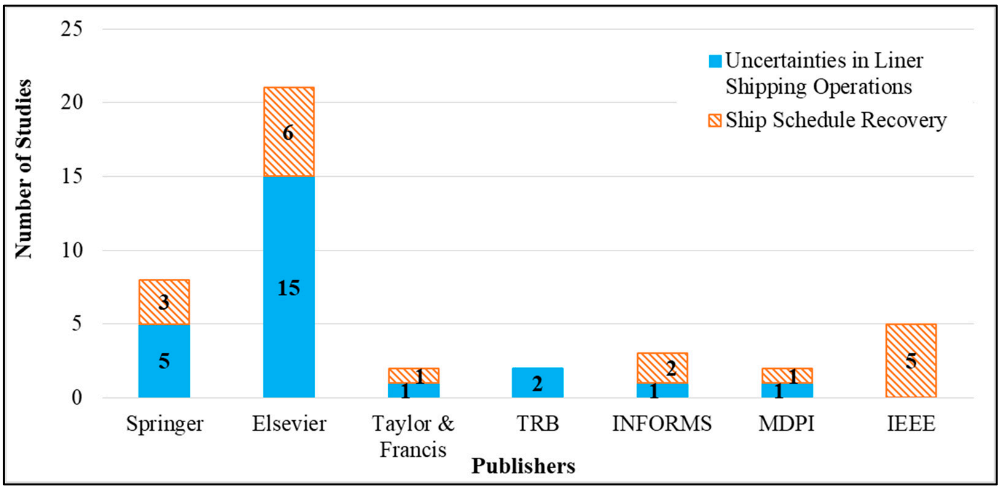


Figure 3. Distribution of the collected studies by publisher.

3. Uncertainties in Liner Shipping Operations

This section of the manuscript provides a detailed evaluation of the state-of-the-art in the area of modeling uncertainties in liner shipping operations with a primary focus on the following aspects. First, a description of a general ship scheduling problem with uncertain ship waiting and handing times at ports is presented. Second, the base mathematical model for the ship scheduling problem with uncertainties is formulated. Third, a detailed review of the relevant studies is provided. Fourth, a concise state-of-the-art summary is outlined, and critical research gaps in the area of modeling uncertainties in liner shipping operations are underlined.

3.1. Problem Description

3.1.1. Liner Shipping Route and Ship Voyage

Liner shipping routes (or port rotations) are used by shipping lines to transfer containers from one port to another. A set of ports for a given liner shipping route will be denoted as $P = \{1, \ldots, n^1\}$ in this study. A liner shipping route can be managed by a single shipping line or several shipping lines (in other words, by a shipping alliance). Each liner shipping route is associated with a pre-determined service frequency, where ships have to visit each port and load/offload containers after a certain number of days. The number of ships that should be allocated for service of a shipping route is proportional to the port service frequency, i.e., more ships should be allocated to the routes that have higher port service frequency (see Section 3.1.4 for more details). After making a round-trip voyage, each ship should return to the first port of call, where the voyage originated. Figure 4 displays a possible liner shipping network with four port rotations. Port rotation "1" includes three ports, port rotation "2" includes five ports, whereas port rotations "3" and "4" are represented by four ports each. In case of port rotation "3", each ship begins its voyage at port "5", then visits ports "8", "9", "10", and returns again to port "5" to complete its voyage. Ships sail between consecutive ports along voyage legs (i.e., voyage leg p is used to connect ports p and $p+1$). In case of port rotation "3", the allocated ships are assumed to sail along voyage leg "8" to reach port "9" from port "8". Ships may visit a given port more than once during a given voyage.

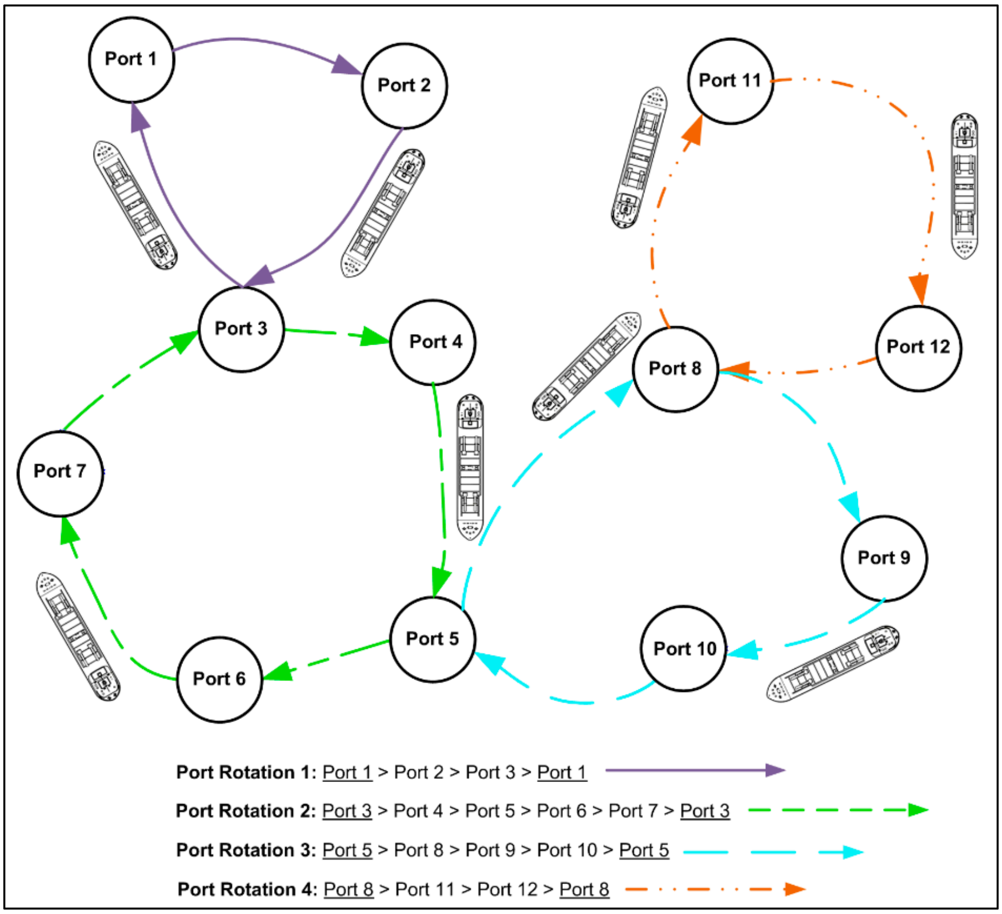


Figure 4. Illustration of an example shipping route.

3.1.2. Ship Service at Ports

Ports of each liner shipping route are generally visited with a particular frequency. Weekly and bi-weekly port visits are viewed as common in the liner shipping industry [32,33,50,51]. Each shipping line has a public schedule of port visits. Service of ships at ports of call is associated with various operations, including the following: (1) transfer of arrived ships to dedicated berthing positions by tug boats; (2) mooring of ships at berthing positions; (3) loading of export containers and offloading of import containers by quay cranes; and (4) transfer of containers between the seaside and the marshaling yard of a marine container terminal. Ships are expected to arrive within a particular time widow (TW) at each port. The arrival TWs are negotiated between the shipping line and each terminal operator. Note that some terminal operators may offer multiple TWs for the arrival of ships, depending on the available ship handling resources and berthing availability [52]. Two attributes are associated with each TW, including the start of the arrival TW at port p ($\tau_p^{st}, p \in P$—hours) and the end of the arrival TW at port p ($\tau_p^{end}, p \in P$—hours).

There are two types of arrival TWs that have been used in the liner shipping literature [53]: (a) hard (or strict) arrival TWs and (b) soft arrival TWs. In case of hard arrival TWs, ships are mandated to arrive within the previously negotiated TWs. In the case of soft TWs, ships are allowed to arrive outside the previously negotiated TWs; however, additional inconvenience costs will be imposed on the shipping line for TW violation. This study assumes TWs to be soft, and a late ship arrival cost ($\kappa_p^{late}, p \in P$ USD/hour) will be imposed for the ships arriving after the end of the negotiated TW. For the ships arriving before the start of the negotiated TW, no penalties will be imposed. However, the ships will have to wait until the start of the negotiated TW. As a part of tactical-level planning of liner shipping operations, along with ship arrival TWs, handling rates have to be negotiated for ships between the shipping line and each terminal operator as well. The handling productivity (measured in number of TEUs loaded/offloaded per hour) is proportional to the handling rate. Let $\kappa_p^{hand}, p \in P$ represent the unit cost associated with container handling at port p (USD/TEU). As stated in the introduction section of this manuscript, marine terminal operators often experience unexpected disruptive events that cause port congestion, which further affects ship waiting and handling times at ports. Therefore, the ship waiting and handling times, denoted as $\widetilde{\boldsymbol{\tau}_p^{wait}}, p \in P$ (hours) and $\widetilde{\boldsymbol{\tau}_p^{hand}}, p \in P$ (hours), respectively, are assumed to be uncertain in this study.

3.1.3. Fuel Consumption Estimation

The fuel cost may comprise a significant portion of the total shipping route service cost. For instance, Ronen [54] reports that the fuel cost can be higher than 75% of the total ship operational costs. Therefore, the amount of fuel required by ships should be accurately estimated for cost-effective ship schedule design. This study assumes that the shipping route will be served by homogeneous ships (i.e., the ships that have similar technical characteristics, including fuel consumption rates). Such an assumption can be viewed as common among the studies on liner shipping operations and ship scheduling [47]. The ship sailing speed and payload are recognized as the major two predictors that dictate the amount of fuel required by ships [15,55,56]. Indeed, ships sailing at higher speeds will require more fuel compared to ships sailing at lower speeds. Furthermore, fully-loaded ships will require more fuel compared to partially-loaded ships. Taking into account the aforementioned considerations, the amount of fuel to be consumed on voyage leg p by the main ship engines ($\boldsymbol{\varphi}_p,\ p \in P$—tons/nmi) can be computed using the following mathematical relationship:

$$\boldsymbol{\varphi}_p = \frac{\gamma(\boldsymbol{s}_p)^{\alpha-1}}{24} \cdot \left(\frac{\boldsymbol{\delta}_p^{sea} \cdot \omega + \delta^{empty}}{\delta^{cap} + \delta^{empty}} \right)^{\frac{2}{3}} \forall p \in P \tag{1}$$

where: α, γ—coefficients associated with the fuel consumption function; $\boldsymbol{s}_p, p \in P$—sailing speed of ships on voyage leg p (knots); $\boldsymbol{\delta}_p^{sea}, p \in P$—number of containers to be carried on voyage leg p (TEUs); ω—average cargo weight within a standard TEU (tons); δ^{empty}—weight of a ship without containers (tons); δ^{cap}—maximum weight of containers that could be loaded on a ship (tons).

Note that fuel consumption coefficients α and γ depend on the ship type. However, the amount of consumed fuel is generally much higher for larger ships that are fully loaded and sail at higher speeds. When selecting the ship sailing speed on each voyage leg of the shipping route, the shipping line has to keep in mind that the maximum ship sailing speed (s^{max}—knots) will be dictated by the engine capacity of deployed ships. Moreover, selection of low sailing speeds (i.e., the phenomenon known as "slow steaming") would reduce fuel consumption and the total fuel cost. However, there is also a minimum sailing speed that could be set for deployed ships (s^{min}—knots), as ships sailing at extremely low speeds pose the risk of main engine deterioration [47,55]. Note that Equation (1) is applicable for the fuel consumption by the main ship engines, whereas the fuel consumption by the auxiliary ship engines typically remains constant during the voyage and is accounted for in the ship operational cost.

3.1.4. Port Service Frequency Determination

Determination of the port service frequency is viewed as a tactical-level liner shipping planning decision [43,47]. The port service frequency is set considering the existing demand for export and import containers and is generally set to meet the target profit margins. The shipping line must ensure that the following mathematical relationship is adhered to in order to maintain the port service frequency established [32,33,47]:

$$24 \cdot \phi \cdot \boldsymbol{q}^{tot} = \sum_{p \in P} \boldsymbol{\tau}_p^{sail} + \sum_{p \in P} \widetilde{\boldsymbol{\tau}_p^{wait}} + \sum_{p \in P} \widetilde{\boldsymbol{\tau}_p^{hand}} \tag{2}$$

where: "24"—number of hours for a one-day time interval; ϕ—agreed frequency of port service (days); $\boldsymbol{q}^{tot}$—number of ships to be deployed (ships); $\boldsymbol{\tau}_p^{sail}, p \in P$—sailing time of ships on voyage leg p (hours); $\widetilde{\boldsymbol{\tau}_p^{wait}}, p \in P$—expected waiting time of ships at port p (hours); $\widetilde{\boldsymbol{\tau}_p^{hand}}, p \in P$—expected handling time of ships at port p (hours).

The left-hand side of Equation (2) is the product of the total number of hours for a one-day time interval, the agreed frequency of port service, and the total number of ships to be deployed. The right-hand side of Equation (2) represents the overall turnaround time of ships, which is estimated as a summation of the overall sailing time of ships, overall expected waiting time of ships at ports, and overall expected handling time of ships at ports. In case the shipping line does not have enough own ships for deployment, additional ships can be charted from other shipping lines in order to ensure the agreed frequency of port service. The following mathematical relationships should be considered by the shipping line when assigning ships for service of a given shipping route:

$$\boldsymbol{q}^{tot} = \boldsymbol{q}^{own} + \boldsymbol{q}^{char} \tag{3}$$

$$\boldsymbol{q}^{own} \leq q^{own-max} \tag{4}$$

$$\boldsymbol{q}^{char} \leq q^{char-max} \tag{5}$$

where: $\boldsymbol{q}^{tot}$—number of ships to be deployed (ships); $\boldsymbol{q}^{own}$number of own ships to be deployed (ships); $\boldsymbol{q}^{char}$—number of chartered ships to be deployed (ships); $q^{own-max}$—maximum number of own ships that could be deployed (ships); $q^{char-max}$—maximum number of chartered ships that could be deployed (ships).

Chartering of ships from other shipping lines incurs an additional ship chartering cost (κ^{char}USD/day), which is typically higher than the cost associated with operating own ships (κ^{oper}—USD/day). To prevent excessive ship chartering costs, the shipping line may decide to increase the ship sailing speed, which will reduce the total ship turnaround time and require fewer ships for deployment. An example of the shipping route service is presented in Figure 5, where a total of four ships are deployed to visit the ports of call. The ships provide weekly port service frequency (i.e., each port is visited every one week or 168 h; $\phi = 7$ days).

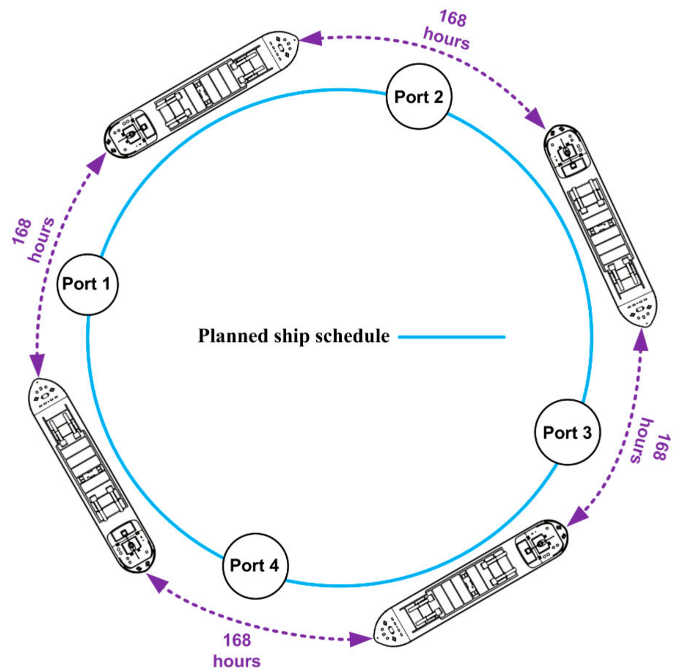


Figure 5. Maintaining the agreed frequency of port service.

3.1.5. Container Inventory Considerations

Sailing speed reduction can assist shipping lines by decreasing the total amount of fuel required for the deployed ships and the total fuel cost as well [57–61]. However, ship sailing speed reduction has certain negative externalities as well. In particular, sailing speed reduction increases the ship transit time and the amount of time containers spend on the ships, which negatively influences the efficiency of liner shipping operations. Therefore, ship schedules should be designed directly taking into consideration container inventory and associated costs. The total cost associated with container inventory ($\boldsymbol{K}^{inv}$—USD) can be computed using the following mathematical relationship [26,32]:

$$\boldsymbol{K}^{inv} = \kappa^{inv} \sum_{p \in P} \delta_p^{sea} \cdot \boldsymbol{\tau}_p^{sail} \tag{6}$$

where: κ^{inv}—unit cost associated with container inventory (USD/hour); $\delta_p^{sea}, p \in P$—number of containers to be carried on voyage leg p (TEUs); $\boldsymbol{\tau}_p^{sail}, p \in P$—sailing time of a ship on voyage leg p (hours).

3.2. Base Mathematical Model

The base mathematical model for the ship scheduling problem with uncertainties (**SSP-U**) can be formulated using the objective function (7) and constraints (8) through (26). Note that for a detailed description of all the notations used in the mathematical models presented in this manuscript, interested readers can refer to Appendix A that accompanies this manuscript. The bold notations are used for decision variables, auxiliary variables, and uncertain/stochastic parameters within the mathematical models, whereas the standard font is used for constant parameters. The proposed **SSP-U** mathematical model assumes that the ship waiting and handling times are uncertain. The **SSP-U** objective function (7) aims to maximize the total profit (**Π**—USD) that will be accumulated by the shipping line from the provided liner shipping service, which is estimated as a difference between the total revenue (***R***—USD) and the total cost associated with the service of the considered shipping route.

$$max\ \boldsymbol{\Pi} = \left[\boldsymbol{R} - \left(\boldsymbol{K}^{hand} + \boldsymbol{K}^{late} + \boldsymbol{K}^{fuel} + \boldsymbol{K}^{oper} + \boldsymbol{K}^{char} + \boldsymbol{K}^{inv}\right)\right] \tag{7}$$

The total cost associated with the service of the considered shipping route includes the following elements: (1) total cost associated with container handling at ports ($\boldsymbol{K}^{hand}$—USD); (2) total cost associated with late ship arrivals ($\boldsymbol{K}^{late}$—USD); (3) total cost associated with fuel consumption ($\boldsymbol{K}^{fuel}$—USD); (4) total cost associated with basic ship operations ($\boldsymbol{K}^{oper}$—USD); (5) total cost associated with chartering of ships ($\boldsymbol{K}^{char}$—USD); and (6) total cost associated with container inventory ($\boldsymbol{K}^{inv}$—USD). The **SSP-U** model includes a total of four groups of constraint sets. The first constraint group, represented by constraints (8) through (11), estimates the sailing time of ships, taking into account the established speed bounds, and the consumption of fuel by the main engines of ships on voyage legs of the considered shipping route. In particular, constraints (8) and (9) assure that the sailing speed of ships remains within the established speed bounds on each voyage leg. Constraints (10) compute the sailing time of ships on each voyage leg based on the voyage leg length and the sailing speed of ships. On the other hand, the consumption of fuel by the main engines of ships on each voyage is computed by constraints (11) based on the sailing speed of ships, coefficients associated with the fuel consumption function, and ship payload.

$$\boldsymbol{s}_p \leq s^{max} \ \forall p \in P \tag{8}$$

$$\boldsymbol{s}_p \geq s^{min} \ \forall p \in P \tag{9}$$

$$\boldsymbol{\tau}_p^{sail} = \frac{l_p}{\boldsymbol{s}_p} \ \forall p \in P \tag{10}$$

$$\boldsymbol{\varphi}_p = \frac{\gamma(\boldsymbol{s}_p)^{\alpha-1}}{24} \cdot \left(\frac{\delta_p^{sea} \cdot \omega + \delta^{empty}}{\delta^{cap} + \delta^{empty}} \right)^{\frac{2}{3}} \ \forall p \in P \tag{11}$$

The second constraint group, represented by constraints (12) through (15), estimates the main time components associated with port operations for the considered shipping route. These time components include the following: (1) arrival time of ships at ports (constraints (12) and (13)); (2) late arrival hours of ships at ports (constraints (14)); and (3) departure time of ships from ports (constraints (15)).

$$\boldsymbol{\tau}_{p+1}^{arr} = \boldsymbol{\tau}_p^{dep} + \boldsymbol{\tau}_p^{sail} \ \forall p \in P, p < n^1 \tag{12}$$

$$\boldsymbol{\tau}_1^{arr} = \boldsymbol{\tau}_p^{dep} + \boldsymbol{\tau}_p^{sail} - 24 \cdot \phi \cdot \boldsymbol{q}^{tot} \ \forall p \in P, p = n^1 \tag{13}$$

$$\boldsymbol{\tau}_p^{late} \geq \boldsymbol{\tau}_p^{arr} - \tau_p^{end} \ \forall p \in P \tag{14}$$

$$\boldsymbol{\tau}_p^{dep} = \boldsymbol{\tau}_p^{arr} + \widetilde{\boldsymbol{\tau}_p^{wait}} + \widetilde{\boldsymbol{\tau}_p^{hand}} \ \forall p \in P \tag{15}$$

The third constraint group, represented by constraints (16) through (19), assures that the established frequency of port service will be maintained for the considered shipping route. In particular, constraints (16) assure that the number of ships to be deployed is sufficient for maintaining the established frequency of port service. Constraints (17) compute the number of ships to be deployed based on the number of own ships to be deployed and the number of chartered ships to be deployed. Constraints (18) assure that the number of own ships to be deployed does not exceed the maximum number of own ships that could be deployed for the considered shipping route. Constraints (19) assure that the number of chartered ships to be deployed does not exceed the maximum number of chartered ships that could be deployed for the considered shipping route.

$$24 \cdot \phi \cdot \boldsymbol{q}^{tot} = \sum_{p \in P} \boldsymbol{\tau}_p^{sail} + \sum_{p \in P} \widetilde{\boldsymbol{\tau}_p^{wait}} + \sum_{p \in P} \widetilde{\boldsymbol{\tau}_p^{hand}} \tag{16}$$

$$\boldsymbol{q}^{tot} = \boldsymbol{q}^{own} + \boldsymbol{q}^{char} \tag{17}$$

$$\boldsymbol{q}^{own} \leq q^{own-max} \tag{18}$$

$$\boldsymbol{q}^{char} \leq q^{char-max} \tag{19}$$

The fourth and the last constraint group, represented by constraints (20) through (26), estimates all the individual cost elements that are required for calculation of the **SSP-U** objective function (7).

$$\boldsymbol{R} = \sum_{p \in P} \kappa_p^{rev} \cdot \boldsymbol{\delta}_p^{port} \tag{20}$$

$$\boldsymbol{K}^{hand} = \sum_{p \in P} \kappa_p^{hand} \cdot \boldsymbol{\delta}_p^{port} \tag{21}$$

$$\boldsymbol{K}^{late} = \sum_{p \in P} \kappa_p^{late} \cdot \boldsymbol{\tau}_p^{late} \tag{22}$$

$$\boldsymbol{K}^{fuel} = \kappa^{fuel} \sum_{p \in P} l_p \cdot \boldsymbol{\varphi}_p \tag{23}$$

$$\boldsymbol{K}^{oper} = \kappa^{oper} \cdot \phi \cdot \boldsymbol{q}^{own} \tag{24}$$

$$\boldsymbol{K}^{char} = \kappa^{char} \cdot \phi \cdot \boldsymbol{q}^{char} \tag{25}$$

$$\boldsymbol{K}^{inv} = \kappa^{inv} \sum_{p \in P} \boldsymbol{\delta}_p^{sea} \cdot \boldsymbol{\tau}_p^{sail} \tag{26}$$

3.3. Review of the Relevant Studies

With regard to ship scheduling, shipping lines must deal with a key challenge—managing timely liner shipping operations. Customers may face increased logistics costs as a result of lengthier waiting periods and delays because of unreliable ship schedules. Notteboom [11] aimed to understand the causes of unreliability in liner shipping services along with the measures that could be taken to improve the reliability of liner shipping services, such as increasing ship size, rearranging the order of ports, port skipping, and adjusting the sailing speed. Vernimmen et al. [62] explored the reasons for the unreliability of liner schedules and the effects they have on the various stakeholders in the supply chain, such as shipping lines, inland transport operators, terminal operators, and shippers. An example case study showed that a manufacturer's capacity to source replacement components from overseas may be affected by the level of schedule unreliability. Previous research on the planning and scheduling of container ship routes assumed an acute market demand, which is not a viable assumption in the actual world. To address this gap in the state-of-the-art, Chuang et al. [63] suggested a planning model for container ship routes that takes into consideration uncertain market demand, shipping time, and berthing time. Using the fuzzy set theory, the article developed a genetic algorithm as a decision support system in which the fitness degree of a shipping route was generated from the fuzzy total profit.

Meng and Wang [64] investigated a short-term ship fleet planning problem in liner shipping for a single shipping line, taking container demand uncertainty into account. The problem was addressed using an integer linear mathematical programming model with chance constraints. The objective was to minimize the total route service cost. The developed chance-constraint programming model was solved with CPLEX. A number of research efforts have been dedicated towards a decrease in bunker consumption (and the associated ship emissions). Nonetheless, the studies on ship routing and scheduling have failed to account for the system's stochastic nature. Qi and Song [65] attempted to fill this gap by developing a mathematical model to reduce fuel consumption while focusing on port time uncertainty. A stochastic approximation strategy based on simulation was used to solve the model. The study also found that reducing the level of service on shorter voyage legs could save fuel consumption. Wang and Meng [7] sought to create a plan that accounts for port operations uncertainties, such as unpredictable waiting times due to port congestion and unknown cargo handling times. The proposed schedule was resilient since it accounted for intrinsic uncertainty in port operations as well as schedule recovery via rapid steaming. In order to address the problem, a mixed-integer stochastic nonlinear programming model was created. The model was then solved using a method that combined a sample average approximation approach, linearization approaches, and a decomposition methodology.

Wang and Meng [66] developed a mixed-integer stochastic nonlinear programming model to maintain the total transit time while minimizing the overall cost. The study explicitly modeled ship fuel consumption, port time uncertainty, and sea contingency. The efficiency of the proposed exact cutting plane-based solution algorithm was validated by extensive computational experiments using realistic data. Di Francesco et al. [67] studied the issue of empty container repositioning in sea transportation networks, taking into account potential uncertainties in port times (e.g., due to various disruptive events). The authors introduced a stochastic programming method that was based on a multi-scenario mathematical model. The provided multi-scenario mathematical approach sought to reduce the total cost. CPLEX was adopted as a solution method. Disruptions are common not just for container shipping, but also for shipping of liquid and dry bulk cargoes. Halvorsen-Weare et al. [68] investigated a real-world liquefied natural gas (LNG) ship scheduling problem, in which the goal was to design robust routes and timetables capturing potential changes in weather circumstances. The study created and tested a solution strategy as well as alternative robustness approaches for scenarios with time horizons ranging from 3 to 12 months. The obtained solutions were evaluated by means of a simulation model in conjunction with a recourse optimization process.

According to Du et al. [69], unexpected severe weather circumstances can have an impact on the voyage of any container ship. Inclement weather, in particular, can have an impact on ship speed and fuel consumption. As a result, the study designed a robust optimization model for the fuel budgeting decision problem, taking into account the influence of severe weather on fuel consumption. To solve the developed mathematical model, a polynomial-time solution methodology was developed. Kepaptsoglou et al. [70] developed a stochastic model to predict the optimum routes for a group of homogeneous container vessels, taking into account sailing time uncertainty caused by severe weather. A chance-constraint formulation was utilized to minimize the total route service cost. A genetic algorithm-based metaheuristic approach was used for the solution. The results of the performed experiments showed that the deployment of a small-size ship fleet was sufficient to provide liner shipping services, even in the presence of small operational delays.

Slow steaming has been widely adopted as an operating approach by shipping lines, since it has proved the efficiency in terms of fuel expense savings. According to the study by Lee et al. [71], slow steaming has certain negative effects as well, primarily increased transit time and unpredictability during the ship voyage. The authors provided a mathematical model for analyzing the links between three important shipping attributes: total bunker cost, shipping time, and cargo delivery reliability. Because of the use of slow steaming, the port time was modeled to be uncertain. Uncertainty in container shipping demand was indicated to be one of the primary concerns that must be accounted for. Ng [72] investigated a container ship deployment problem with stochastic dependencies in container shipping demand, where the variance and mean of the maximum container demand were required to be known. The objective function attempted to minimize the total route service cost. CPLEX was used to solve the mathematical formulation.

Uncertain port service and sailing times owing to bad weather could have a significant impact on ship timetables, particularly during the winter season. Norlund et al. [73] suggested a simulation-optimization-based framework for weekly supply ship scheduling that takes into account the cost, emission, and robustness factors. The goal was to reduce the overall route service cost. It was demonstrated that a greater emphasis on robustness was predicted to result in higher costs and emissions during the winter season. Song et al. [74] focused on liner shipping scheduling under port time uncertainty. The tactical problem aimed to optimize the shipping emission, service reliability, and planned cost. A non-dominated sorting genetic algorithm II (NSGA-II) was applied to solve the model. Based on the numerical results, the deployment of larger ships could be an effective approach to address the uncertain demand. However, it could be an expensive choice because larger ships have higher operational costs.

Wang [75] stated that a series of container ships may not have the same capacity. As a result, the order in which ships arrive affects the number of stacked and delayed containers at ports. The study thus tried to identify the sequence of ships in a string in order to minimize the overall container delay. Experiments revealed that improving ship sequences might save the world's liner services $6 million per year. Aydin et al. [76] investigated a liner shipping speed optimization and bunkering problem characterized by uncertain port times, with the goal of minimizing fuel consumption while maintaining schedule consistency. The study formulated a dynamic programming model for the decision problem considered. Numerical experiments using real-world data revealed a considerable reduction in fuel consumption when compared to the state-of-the-art approaches. Song et al. [77] aimed to optimize service scheduling, ship sailing speed, and ship deployment in a liner shipping service with port and sea uncertainty. Three service-reliability key performance indicators (KPIs) and two cost-related KPIs were defined. The two cost KPIs represented the shipper and the carrier, whereas the three reliability KPIs represented the terminal operator, the shipper, and the carrier. To solve the provided multi-objective mathematical model, a multi-objective metaheuristic algorithm was used in the study.

Ng and Lin [78] addressed the ship fleet deployment problem in liner shipping, highlighting that only conditional information on container shipping demand could be available. A mathematical formulation was devised with the objective of minimizing the total route service cost. CPLEX was used to solve the developed mathematical formulation. In contrast to road and rail transportation, inland shipping is gaining popularity as a more environmentally friendly and sustainable means of transportation. However, in order to compete in the shipping industry, an inland shipping company must provide a rapid, stable, and cost-effective service. Nonetheless, varying stream flow speeds between ports and uncertain transit times induced by dam lock operations could make the inland ship schedule design difficult. Tan et al. [79] devised a joint ship schedule and speed optimization problem while accounting for uncertainty in dam transit time. A bi-objective chance constraint programming model was then created, with the goal of minimizing both fuel consumption and ship total travel time.

Gurel and Shadmand [80] investigated a liner ship scheduling problem with a heterogeneous fleet while accounting for port handling and waiting time uncertainty in order to minimize fuel consumption. A chance-constrained nonlinear mixed-integer programming model was used to solve the problem. The experimental results indicated that assigning various service levels to port–ship type pairs was more efficient than assigning equal service levels to all pairs. In order to develop new mathematical models for liner shipping service design, Tierney et al. [81] used empirical ship travel time data from a real liner shipping network. In particular, the study proposed three mathematical models, including the following: (1) the design speed model; (2) the optimized speed model; and (3) the optimal speed with maximum transit time model. The models used a buffer time to meet the desired level of service for customers. The proposed models were the first to integrate the support for variable ship speeds in the service design. Using the model for tactical decision support, the researchers showed that it could be used not only for service design but also in negotiations with customers concerning maximum demand transit times and costs.

The study by Liu et al. [82] focused on liner ship speed optimization and bunkering under uncertain container demand. This problem was approached using nonlinear programming and a two-stage stochastic model. The complex bunker consumption function was approximated using piecewise linear functions to reduce the problem's complexity. The resulting model was then solved using an L-shaped approach, a sample average approximation based on scenario reduction, and a classic sample average approximation. The L-shape technique was found to be more advantageous in terms of both solution quality and computation time. Ding and Xie [83] suggested a two-stage stochastic nonlinear integer programming approach for liner ship scheduling and routing with unexpected shipping delays. The combination of schedule-sensitive shipping demand and unpredictable arrival time factors resulted in a nonlinear model formulation. Nominal delay variables were introduced to the model to produce a comparable linear integer programming counterpart. A Bender's decomposition method was utilized to solve the linearized problem.

Liu et al. [84] introduced a ship scheduling technique with full voyage constraints to increase the efficiency of operating out-wharf and in-wharf ships at seaports, while taking into account the characteristics of uncertain ship speeds. The study was able to simplify the mathematical model with the use of multi-time restrictions by selecting the minimal safe time intervals. To propose a method for determining the passable time window, the time window concept was linked with the tide height and ship drafts. Additionally, nonlinear global constraints were discretely converted into linear constraints. The developed genetic algorithm sought to reduce the average waiting time for the modified vessel scheduling problem. According to the findings, the reformulated and simplified mathematical model had a lower relative error than conventional priority scheduling rules and could be utilized to successfully boost ship scheduling efficiency while still ensuring traffic safety.

3.4. Literature Summary and Research Gaps

3.4.1. Summary of Findings

A detailed summary of the reviewed studies on uncertainties in liner shipping operations is presented in Table 1 focusing on the following information: (1) authors; (2) sailing speed assumptions; (3) port time assumptions; (4) objective function adopted; (5) components of the objective function adopted; (6) uncertain elements considered; (7) solution approach deployed; and (8) particular notes along with important study considerations. Furthermore, Figure 6 provides a distribution of the reviewed studies by model objective, objective components, uncertain elements, and solution approach. After a thorough review of the literature on uncertainties in liner shipping operations, it can be concluded that a substantial number of studies assumed the ship sailing speed to be uncertain (a total of 44.0%). On the other hand, 68% of studies modeled uncertain port times, mostly focusing on the port handling time uncertainty (see Table 1).

Table 1. Summary of the reviewed studies on uncertainties in liner shipping operations.

a/a	Authors	Sailing Speed	Port Time	Objective	Objective Components	Uncertain Elements	Solution Approach	Notes/Important Considerations
1	Notteboom (2006) [11]	N/A	N/A	Assess the causes that might influence the reliability of shipping services between Northern Europe and East Asia	N/A	N/A	Case Study	Reliability of ship schedules
2	Vernimmen et al. (2007) [62]	N/A	N/A	Assess the causes of liner schedule unreliability and how these causes could impact supply chain players	N/A	N/A	Case Study	Reliability of ship schedules
3	Chuang et al. (2010) [63]	U	U	Total profit maximization	REV; TFC; TOC; TPC	Handling time; Sailing time; Container demand	Metaheuristic	Proposing a fuzzy Genetic Algorithm for liner shipping planning
4	Meng and Wang (2010) [64]	F	U	Total route service cost minimization	MSC; REV; TOC	Container demand	CPLEX	Ship fleet planning with uncertainty in container demand
5	Qi and Song (2012) [65]	V	U	Total route service cost minimization	TFC; TVC	Handling time	Iterative Optimization Algorithm; Sample Average Approximation	Minimizing the total expected fuel consumption (and emissions)
6	Wang and Meng (2012) [7]	V	U	Total route service cost minimization	TFC; TOC; TVC	Waiting time; Handling time	Iterative Optimization Algorithm	Consideration of waiting time and handling time uncertainties due to port congestion
7	Wang and Meng (2012) [66]	U	U	Total route service cost minimization	TFC; TOC	Waiting time; Handling time; Sailing time	Iterative Optimization Algorithm	Sea contingency time and uncertainty in port time
8	Di Francesco et al. (2013) [67]	V	U	Total route service cost minimization	MSC; TIC; TFC; TOC; TPC; TVC	Waiting time; Handling time; Container demand	CPLEX	Consideration of uncertain port service times and empty container repositioning
9	Halvorsen-Weare et al. (2013) [68]	U	U	Total route service cost minimization	MSC; TIC; TFC; TOC; TPC; TVC	Sailing time; Demand	Xpress-IVE	Considered changing weather conditions
10	Du et al. (2015) [69]	U	F	Total fuel consumption minimization	MSC	Fuel consumption	Iterative Optimization Algorithm	Considering the impacts of adverse weather on the total fuel consumption

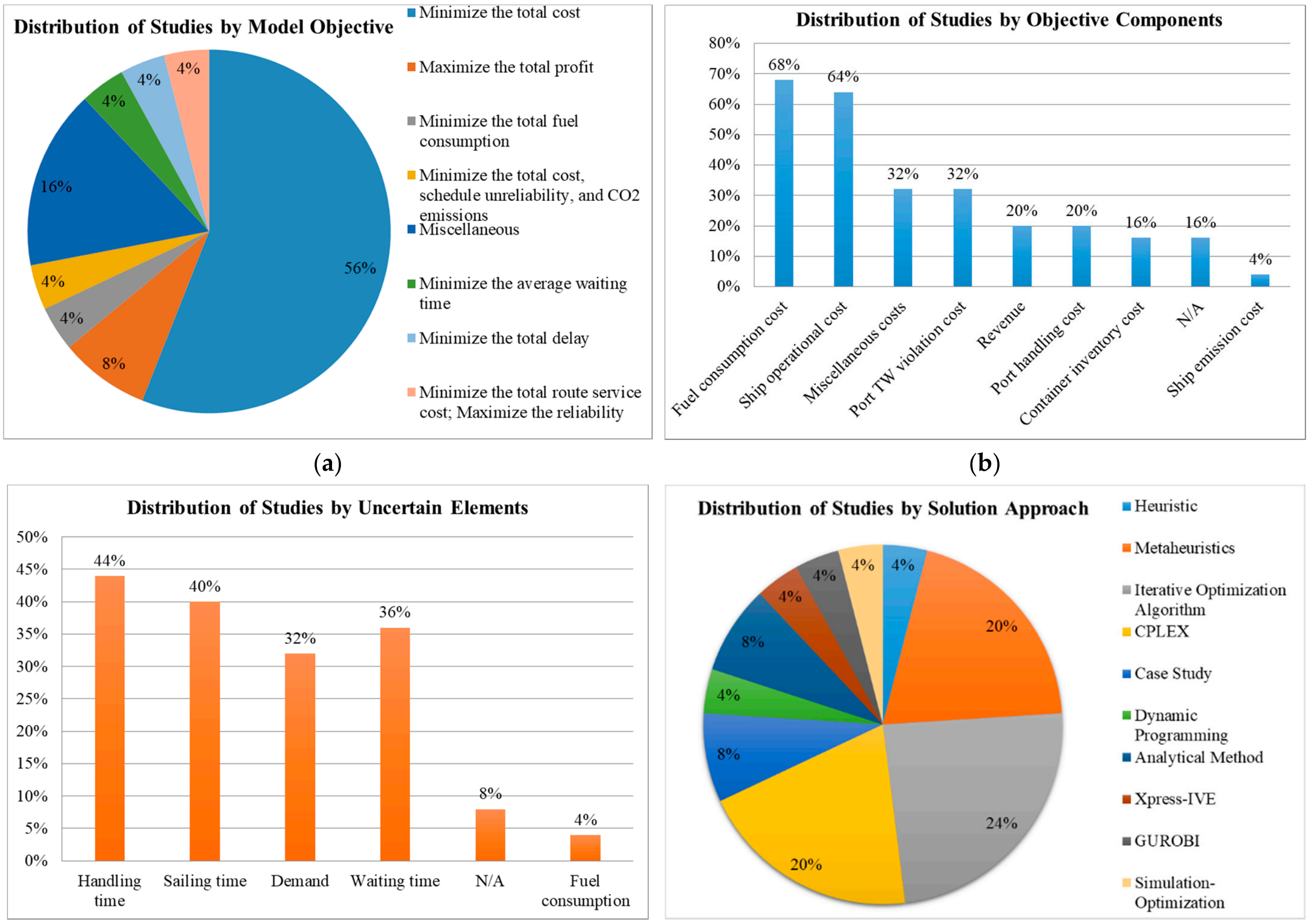
Table 1. *Cont.*

a/a	Authors	Sailing Speed	Port Time	Objective	Objective Components	Uncertain Elements	Solution Approach	Notes/Important Considerations
11	Kepaptsoglou et al. (2015) [70]	U	F	Total route service cost minimization	TFC; TOC; TPC	Sailing time	Metaheuristic	Consideration of potential impacts of severe weather on ship sailing times
12	Lee et al. (2015) [71]	V	U	Analyze the relationship amongst shipping time, bunker cost, and cargo delivery reliability	TFC	Waiting time; Handling time	Analytical Method	Proposed a methodology for ship scheduling with guaranteed reliability of cargo delivery
13	Ng (2015) [72]	F	U	Total route service cost minimization	MSC; REV; TOC	Container demand	CPLEX	Consideration of uncertain shipping demand in ship fleet deployment
14	Norlund et al. (2015) [73]	U	U	Total route service cost minimization	TFC; TOC	Waiting time; Handling time; Sailing time	Simulation-Optimization	Acceptable levels of emissions and costs could be achieved with the adequate robustness level
15	Song et al. (2015) [74]	V	U	Total route service cost minimization; Average schedule unreliability minimization; Annual total CO_2 emission minimization	MSC; TEC; TFC; TOC; TPC; TVC	Waiting time; Handling time	Metaheuristic	Developing a method to optimize the multiple objectives simultaneously
16	Wang (2015) [75]	F	U	Total delay minimization	N/A	Container demand	Heuristic	Consideration of heterogeneous fleet and container demand uncertainty
17	Aydin et al. (2017) [76]	V	U	Total route service cost minimization	TFC; TVC	Waiting time; Handling time	Dynamic Programming	Speed bunkering and optimization under port time uncertainty
18	Song et al. (2017) [77]	U	U	Total route service cost minimization; Reliability maximization	MSC; TFC; TIC; TOC; TVC	Waiting time; Handling time; Sailing time	Metaheuristic	A multi-objective model consisted of three service-reliability KPIs and two cost-related KPIs
19	Ng and Lin (2018) [78]	F	U	Total route service cost minimization	MSC; REV; TOC	Container demand	CPLEX	Conditional information was assumed to be available for container demand

Table 1. *Cont.*

a/a	Authors	Sailing Speed	Port Time	Objective	Objective Components	Uncertain Elements	Solution Approach	Notes/Important Considerations
20	Tan et al. (2018) [79]	U	F	Total fuel consumption cost minimization; Total ship turnaround time minimization	TFC; TOC	Sailing time	Analytical Method	Joint service schedule design and ship sailing speed optimization problem for inland shipping
21	Gurel and Shadmand (2019) [80]	V	U	Total route service cost minimization	TFC	Waiting time; Handling time	CPLEX	Heterogeneous ship fleet considerations
22	Tierney et al. (2019) [81]	U	V	Total route service cost minimization	TFC; TOC	Sailing time	GUROBI	Ship journey times were examined for a real-life liner shipping network
23	Liu et al. (2020) [82]	V	U	Total route service cost minimization	TFC; TIC; TOC	Container demand	Iterative Optimization Algorithms	Solving liner ship bunkering and speed optimization problem
24	Ding and Xie (2021) [83]	U	V	Total profit maximization	REV; TFC; TOC; TVC	Sailing time	Iterative Optimization Algorithm	Balancing chances of unexpected delays and tight timelines
25	Liu et al. (2021) [84]	U	V	Average waiting time minimization	N/A	Sailing time	Metaheuristic	Introduced the notion of a minimum safety time interval (MSTI) in order to decrease the number of constraints

Notes: ***Sailing Speed and Port Time*** [V—Variable; F—Fixed; U—Uncertain]; ***Objective Components*** [MSC—Miscellaneous Costs; REV—Total Revenue; TEC—Total Ship Emission Cost; TFC—Total Fuel Consumption Cost; TIC—Total Container Inventory Cost; TOC—Total Ship Operational Cost; TPC—Total Port Handling Cost; TVC—Total Cost Associated with Violation of Port Time Windows].



(c) (d)

Figure 6. Distribution of the reviewed studies on uncertainties in liner shipping operations by various attributes: (**a**) model objective; (**b**) objective components; (**c**) uncertain elements; and (**d**) solution approach.

As for the objective functions adopted, the majority of studies (more than 50%) aimed to minimize the total cost of route service, mainly considering fuel consumption cost, ship operational cost, and port TW violation cost (see Figure 6). Only two studies focused on the total profit maximization [63,83]. The analysis of the reviewed studies also shows that single-objective mathematical formulations were common (see Table 1). Only Song et al. [74], Song et al. [77], and Tan et al. [79] presented multi-objective mathematical formulations. In particular, the study by Song et al. [74] aimed to minimize the total cost of route service, average schedule unreliability, and annual CO_2 emissions. Song et al. [77] developed a multi-objective optimization model, where the first objective minimized the total cost of route service, whereas the second one aimed to maximize the schedule reliability.

On the other hand, Tan et al. [79] proposed a bi-objective model, minimizing the total fuel consumption cost and the total turnaround time of ships. The studies conducted by Notteboom [11] and Vernimmen et al. [62] did not propose any mathematical formulations for modeling uncertainties in liner shipping operations and solely focused on the review of factors that could potentially influence the reliability of liner shipping services. As for the solution methods adopted, iterative optimization algorithms were identified to be the most popular methods for the studies on uncertainties in liner shipping operations (see Figure 6). A total of 20% of studies relied on metaheuristic algorithms. Furthermore, a significant number of research efforts deployed exact optimization solvers (e.g., CPLEX, GUROBI, and Xpress-IVE).

3.4.2. Limitations and Future Research Needs

The research gaps and a number of shortcomings in the existing studies on uncertainties in liner shipping operations have been identified. These shortcomings and the future research that is required to bridge these gaps are as follows:

- ➢ More detailed and accurate historical data for liner shipping operations are required to model uncertainties associated with the main liner shipping processes and assess various mitigation strategies. The collected historical data can be further used in the development of statistical distributions for uncertain container demand, port time, and sailing time [68,81].
- ➢ Future studies should concentrate on more detailed modeling of uncertain components in liner shipping operations [74]. For instance, the port time component can be disaggregated into various sub-components (e.g., port waiting time, handling time associated with offloading import containers, handling time associated with loading export containers). The effects of uncertainties can be further assessed for each sub-component.
- ➢ A detailed evaluation of the existing studies on uncertainties in liner shipping operations indicates that many studies strictly concentrate on one source of uncertainties (i.e., uncertainty in demand or uncertainty in sailing time or uncertainty in port handling time or uncertainty in port waiting time). Holistic models that emulate multiples sources of uncertainties at the same time should be further explored by future studies.
- ➢ Reliability of liner shipping services can be affected by a variety of factors [11,62], including geographical characteristics, the average age of deployed ships, previous maintenance activities of deployed ships, available handling resources of terminal operators and inland operations, and others. Future research should continue investigating the effects of these factors on liner shipping services and directly consider them for planning purposes.
- ➢ Innovative policies should be explored to offset the effects of uncertainties in liner shipping operations. Dynamic decision-making policies can be promising [71]. As an example, delays due to uncertainties in sailing time could be mitigated by adjusting the ship sailing speed on consecutive voyage legs of a shipping route. However, the ship sailing speed adjustment decision should be made by taking into account other important operational factors (e.g., the number of remaining ports to be visited in a round voyage; increasing fuel cost due to speeding up the ships).
- ➢ One of the common limitations in the existing liner shipping studies consists in the fact that the impacts of weather conditions are not directly accounted for when planning ship sailing speed decisions [76]. Future research efforts must focus on the development of models that directly capture the expected weather conditions on voyage legs when making ship sailing speed decisions.
- ➢ Time-dependent port waiting and handling times should be taken into account in future studies. Waiting and handling times vary significantly at the ports depending on the day of the week and the time of day [80]. Ship arrivals should be planned for the time periods with a lower risk of congestion and port time delays.
- ➢ Future studies should investigate various alternatives for mitigating the effects of significant delays during a ship voyage. In some instances, port skipping or partial loading/offloading of ships might be a promising decision in order to prevent the propagation of delays throughout the entire liner shipping network [81].
- ➢ Strict port arrival TWs may not be feasible for shipping routes that often encounter uncertainties. Therefore, explicit modeling of soft arrival TWs, where ships are allowed to arrive outside the previously negotiated TW but penalized for TW violations, could be studied more as a part of future research [81].
- ➢ It is known that fuel prices fluctuate regularly, and different ships need different types of fuel (e.g., ships sailing inside emission control areas must use low-sulfur fuel—[85–89]). Furthermore, ship sailing speed and fuel consumption are often subject to uncertainties [69]. Therefore, future studies should develop more compre-

hensive liner shipping operations planning models, which directly capture fuel price fluctuations, ship sailing speed uncertainty (and the associated fuel consumption uncertainty), fuel switching, and effective refueling policies.

4. Ship Schedule Recovery

For many years, operations research (OR) methods have been widely employed in the aviation industry [90–92]. Initially, OR was utilized exclusively during the planning phase. However, during the last two decades, OR became popular within the disruption management tools to be used in real time and ensure that the intended airline schedule is executed [92,93]. There are evident parallels between the airline and liner shipping industries [2,94]. Many airline and liner shipping services adopt the hub-and-spoke model for their operations. The operations are planned aiming to minimize the total delays in the delivery of cargo (or passengers in case of planning passenger aircraft operations). A variety of recovery strategies can be used in the airline industry to offset the negative impacts of disruptions, including flight cancellations, adding arcs to discourage deviations from aircraft routing, incorporation of delays, and aircraft flying speed adjustments [95–98]. Some of the recovery strategies used in the airline industry can be applied in the liner shipping industry as well to effectively respond to disruptive events [99].

This section of the manuscript provides a detailed evaluation of the state-of-the-art in the area of ship schedule recovery. First, a description of a general ship schedule recovery problem is presented. Second, the base mathematical models for the ship schedule recovery problem with various recovery options are formulated (including sailing speed adjustment, handling rate adjustment, port skipping, and port skipping with container diversion). Third, a detailed review of the relevant studies is provided. Fourth, a concise state-of-the-art summary is outlined, and critical research gaps in the area of ship schedule recovery are underlined.

4.1. Problem Description

Unlike the ship schedule design problem, which is viewed as a tactical-level decision problem, the ship schedule recovery problem is an operational level (often real-time) decision problem [43,47]. Therefore, certain components in the ship schedule recovery problem are treated as parameters, not variables that are used in the tactical-level planning models. These components include the following: (1) arrival time of ships at ports for the original ship schedule ($\tau_p^{arr}, p \in P$—hours); (2) number of own ships to be deployed for the original ship schedule ($\overline{q^{own}}$—ships); (3) number of chartered ships to be deployed for the original ship schedule ($\overline{q^{char}}$—ships); (4) number of containers to be handled at ports ($\overline{\delta_p^{port}}, p \in P$—TEUs); (5) sailing speed of ships on voyage legs for the original ship schedule ($s_p, p \in P$—knots); and (6) total profit that was expected to be accumulated by the shipping line for the original ship schedule (Π^0—USD).

Disruptions can occur on voyage legs of the shipping route and/or at ports of call. Let $\widetilde{\boldsymbol{\tau}_p^{d-port}}, p \in P$ (hours) and $\widetilde{\boldsymbol{\sigma}_p^{d-sea}}, p \in P$ (knots) be the expected duration for a disruption at port p and the expected change in sailing speed of ships due to a disruption on voyage leg p, respectively. In order to offset the effects of disruptions on the ship schedule, the shipping line is assumed to be able to adopt the following ship schedule recovery strategies (see Figure 7): (a) sailing speed adjustment; (b) handling rate adjustment; (c) port skipping; and (d) port skipping and container diversion. An illustrative example of the sailing speed adjustment strategy is showcased in Figure 7a, where a disruptive event happened on the voyage leg connecting ports "2" and "3". In order to compensate for the delays due to a disruption at sea, the shipping line increased the ship sailing speed on the voyage leg connecting ports "3" and "4" from 18 knots to 24 knots. Moreover, the ship sailing speed was increased from 17 knots to 23 knots on the voyage leg connecting ports "4" and "1" as well. Ship sailing speed adjustment is generally viewed as an effective recovery option to offset small to moderate delays during the voyage but incurs additional fuel costs.

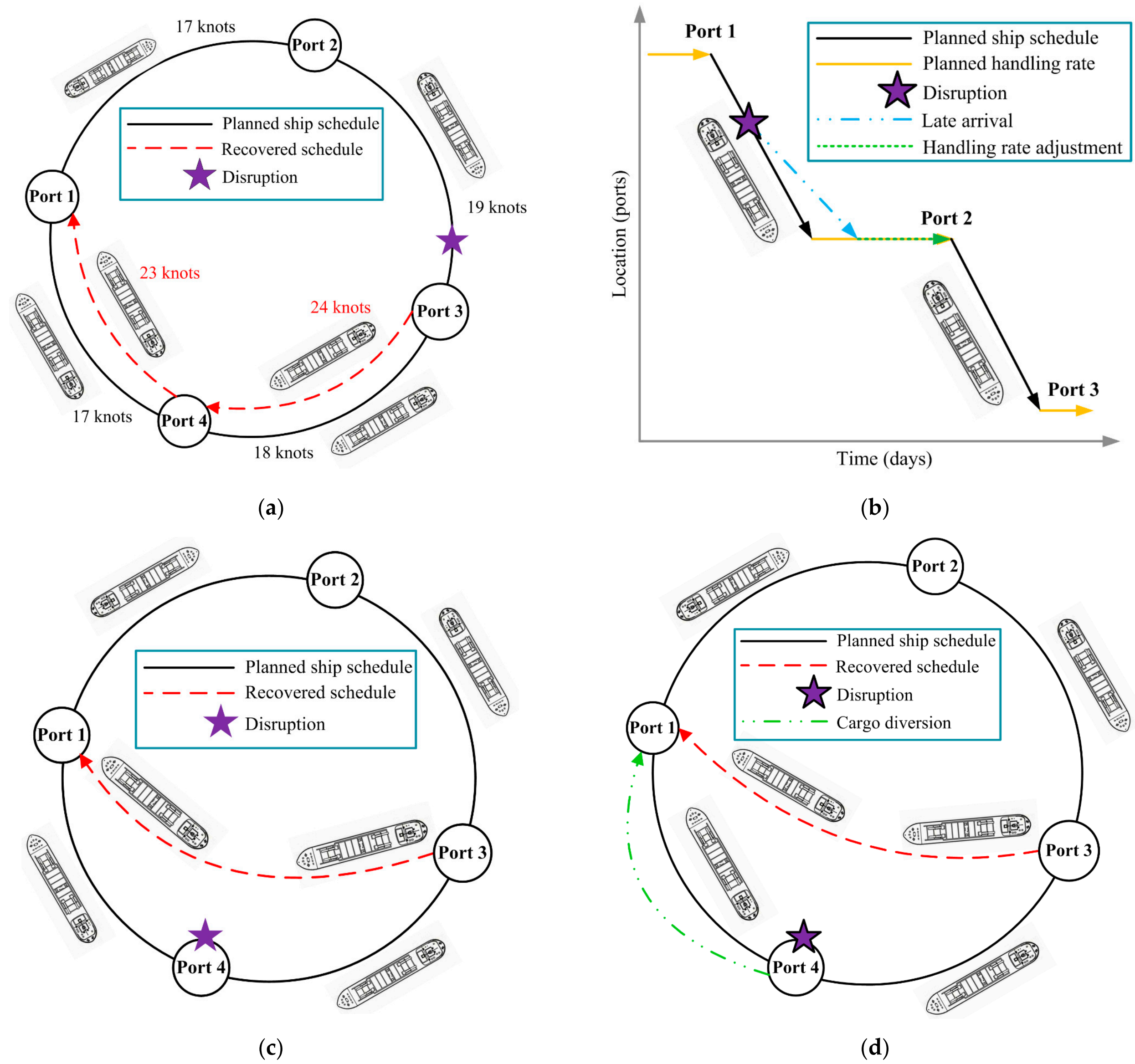


Figure 7. Ship schedule recovery options considered: (**a**) sailing speed adjustment; (**b**) handling rate adjustment; (**c**) port skipping; and (**d**) port skipping and container diversion.

An illustrative example of the handling rate adjustment strategy is showcased in Figure 7b, where a disruptive event happened on the voyage leg connecting ports "1" and "2". This disruptive event caused a late arrival at port "2". In order to compensate for the delays due to a disruption at sea, the shipping line requested a handling rate with a higher handling productivity (when compared to the originally negotiated handling rate). Such a recovery option allowed the ship to leave port "2" in a timely manner and sail to port 3" following the original schedule. Handling rate adjustment is generally viewed as an effective recovery option to offset small to moderate delays during the voyage but incurs additional port handling costs ($\kappa_{ph}^{hand}, p \in P, h \in H_p$—USD/TEU, where $H_p = \left\{1, \ldots, n_p^2\right\}, p \in P$ is a set of handling rates that can be requested by the shipping line at port p). Moreover, selection of this recovery option depends on the handling equipment availability at ports (e.g., some terminal operators may not be able to provide higher handling productivity).

An illustrative example of the port skipping strategy without container diversion is showcased in Figure 7c, where a disruptive event happened at port "4". The ship was directed to sail from port "3" directly to port "1" without stopping at port "4", which experienced a disruption. Port skipping is generally viewed as an effective recovery option to offset large delays during the voyage but incurs additional costs due to previously reserved handling equipment ($\kappa_p^{skip}, p \in P$—USD) and misconnected cargo ($\kappa_p^{mis}, p \in P$—USD/TEU).

An illustrative example of the port skipping strategy with container diversion is showcased in Figure 7d, where a disruptive event happened at port "4". The ship was directed to sail from port "3" directly to port "1" without stopping at port "4", which experienced a disruption. However, the export containers that had to be loaded at port "4" are diverted to port "1" via the intermodal network. Furthermore, the import containers that had to be offloaded at port "4" can be offloaded at port "1" and delivered to the intended customers via the intermodal network as well. Similar to port skipping, port skipping with container diversion is generally viewed as an effective recovery option to offset large delays during the voyage but incurs additional costs due to previously reserved handling equipment and misconnected cargo. Moreover, the port where the containers will be diverted should have adequate container terminal capacity ($\delta_p^{term}, p \in P$—TEUs) and inland transport capacity ($\delta_p^{land}, p \in P$—TEUs) to ensure that the diverted container demand will be effectively accommodated. Nevertheless, unlike the port skipping strategy, the port skipping strategy with container diversion allows delivery of containers to the intended customers despite port skipping.

4.2. Base Mathematical Models

This section presents the base mathematical models for ship schedule recovery with the following recovery strategies: (a) sailing speed adjustment; (b) handling rate adjustment; (c) port skipping; and (d) port skipping and container diversion.

4.2.1. Sailing Speed Adjustment

The base mathematical model for the ship schedule recovery with sailing speed adjustment (**SSR-SSA**) can be formulated using the objective function (27) and constraints (28) through (48). The **SSR-SSA** objective function (27) aims to minimize the total loss of profit that will be endured by the shipping line as a result of disruptions at the considered shipping route. The total profit loss is estimated as a difference between the total profit that was expected to be accumulated by the shipping line for the original ship schedule (Π^0—USD) and the total profit that will be accumulated by the shipping line for the recovered schedule of ships ($\overline{\boldsymbol{\Pi}}$—USD).

$$min \left[\Pi^0 - \overline{\boldsymbol{\Pi}}\right] \tag{27}$$

The **SSR-SSA** model includes a total of three groups of constraint sets. The first constraint group, represented by constraints (28) through (32), estimates the recovered sailing time of ships, considering potential sailing speed adjustment to compensate for the effects of disruptions, and the recovered consumption of fuel by the main engines of ships on voyage legs of the considered shipping route. In particular, constraints (28) compute the recovered sailing speed of ships on each voyage leg, considering the expected change in sailing speed of ships due to a disruption and potential ship sailing speed adjustment. Note that constraints (28) assume that the ship sailing speed adjustment strategy could not be implemented on the voyage leg that experienced a disruption. Constraints (29) and (30) assure that the recovered sailing speed of ships remains within the established speed bounds on each voyage leg. Constraints (31) compute the recovered sailing time of ships on each voyage leg based on the voyage leg length and the recovered sailing speed of ships. Constraints (32) calculate the recovered consumption of fuel by the main engines of ships on each voyage based on the recovered sailing speed of ships, coefficients associated with the fuel consumption function, and ship payload.

$$\overline{\boldsymbol{s}_p} \leq s_p + \widetilde{\boldsymbol{\sigma}_p^{d-sea}} \cdot \widetilde{\boldsymbol{z}_p^{sea}} + \boldsymbol{\sigma}_p^{sea} \cdot \left(1 - \widetilde{\boldsymbol{z}_p^{sea}}\right) \forall p \in P \tag{28}$$

$$\overline{\boldsymbol{s}_p} \leq s^{max} \;\forall p \in P \tag{29}$$

$$\overline{\boldsymbol{s}_p} \geq s^{min} + \widetilde{\boldsymbol{\sigma}_p^{d-sea}} \cdot \widetilde{\boldsymbol{z}_p^{sea}} \;\forall p \in P \tag{30}$$

$$\overline{\boldsymbol{\tau}_p^{sail}} = \frac{l_p}{\overline{\boldsymbol{s}_p}} \;\forall p \in P \tag{31}$$

$$\overline{\boldsymbol{\varphi}_p} = \frac{\gamma\left(\overline{\boldsymbol{s}_p}\right)^{\alpha-1}}{24} \cdot \left(\frac{\delta_p^{sea} \cdot \omega + \delta^{empty}}{\delta^{cap} + \delta^{empty}}\right)^{\frac{2}{3}} \;\forall p \in P \tag{32}$$

The second group of constraints, which is represented by constraints (33) through (40), estimates the main time components associated with port operations that include the following: (1) recovered arrival time of ships at ports (constraints (33) and (34)); (2) recovered handling time of ships at ports (constraints (35)), considering the expected duration of disruptions; (3) recovered waiting time of ships at ports (constraints (36) and (37)); (4) recovered late arrival hours of ships at ports (constraints (38)); (5) recovered departure time of ships from ports (constraints (39)); and (6) turnaround time of ships for the recovered ship schedule (constraints (40)).

$$\overline{\boldsymbol{\tau}_{p+1}^{arr}} = \overline{\boldsymbol{\tau}_p^{dep}} + \overline{\boldsymbol{\tau}_p^{sail}} \;\forall p \in P, p < n^1 \tag{33}$$

$$\overline{\boldsymbol{\tau}_1^{arr}} = \overline{\boldsymbol{\tau}_p^{dep}} + \overline{\boldsymbol{\tau}_p^{sail}} - \overline{\boldsymbol{\tau}^{stt}} \;\forall p \in P, p = n^1 \tag{34}$$

$$\overline{\boldsymbol{\tau}_p^{hand}} = \frac{\overline{\delta_p^{port}}}{\chi_p} + \widetilde{\boldsymbol{\tau}_p^{d-port}} \cdot \widetilde{\boldsymbol{z}_p^{port}} \;\forall p \in P \tag{35}$$

$$\overline{\boldsymbol{\tau}_{p+1}^{wait}} \geq \tau_{p+1}^{st} - \overline{\boldsymbol{\tau}_p^{dep}} - \overline{\boldsymbol{\tau}_p^{sail}} \;\forall p \in P, p < n^1 \tag{36}$$

$$\overline{\boldsymbol{\tau}_1^{wait}} \geq \tau_1^{st} - \overline{\boldsymbol{\tau}_p^{dep}} - \overline{\boldsymbol{\tau}_p^{sail}} + \overline{\boldsymbol{\tau}^{stt}} \;\forall p \in P, p = n^1 \tag{37}$$

$$\overline{\boldsymbol{\tau}_p^{late}} \geq \overline{\boldsymbol{\tau}_p^{arr}} - \tau_p^{arr} \;\forall p \in P \tag{38}$$

$$\overline{\boldsymbol{\tau}_p^{dep}} = \overline{\boldsymbol{\tau}_p^{arr}} + \overline{\boldsymbol{\tau}_p^{wait}} + \overline{\boldsymbol{\tau}_p^{hand}} \;\forall p \in P \tag{39}$$

$$\overline{\boldsymbol{\tau}^{stt}} = \sum_{p \in P} \overline{\boldsymbol{\tau}_p^{sail}} + \sum_{p \in P} \overline{\boldsymbol{\tau}_p^{wait}} + \sum_{p \in P} \overline{\boldsymbol{\tau}_p^{hand}} \tag{40}$$

The third and the last constraint group, represented by constraints (41) through (48), estimates all the individual cost elements of the recovered schedule of ships that are required for calculation of the **SSR-SSA** objective function (27), including the following: (1) total revenue that will be accumulated by the shipping line ($\overline{R}$—USD); (2) total cost associated with container handling at ports ($\overline{K^{hand}}$—USD); (3) total cost associated with late ship arrivals ($\overline{\boldsymbol{K}^{late}}$—USD); (4) total cost associated with fuel consumption ($\overline{\boldsymbol{K}^{fuel}}$—USD); (5) total cost associated with basic ship operations ($\overline{K^{oper}}$—USD); (6); total cost associated with chartering of ships ($\overline{K^{char}}$—USD); (7) total cost associated with container inventory ($\overline{\boldsymbol{K}^{inv}}$—USD); and (8) total profit that will be accumulated by the shipping line ($\overline{\boldsymbol{\Pi}}$—USD).

$$\overline{R} = \sum_{p \in P} \kappa_p^{rev} \cdot \overline{\delta_p^{port}} \tag{41}$$

$$\overline{K^{hand}} = \sum_{p \in P} \kappa_p^{hand} \cdot \overline{\delta_p^{port}} \tag{42}$$

$$\overline{\boldsymbol{K}^{late}} = \sum_{p \in P} \kappa_p^{late} \cdot \overline{\boldsymbol{\tau}_p^{late}} \tag{43}$$

$$\overline{\boldsymbol{K}^{fuel}} = c^{fuel} \sum_{p \in P} l_p \cdot \overline{\boldsymbol{\varphi}_p} \tag{44}$$

$$\overline{K^{oper}} = \kappa^{oper} \cdot \phi \cdot \overline{q^{own}} \tag{45}$$

$$\overline{K^{char}} = \kappa^{char} \cdot \phi \cdot \overline{q^{char}} \tag{46}$$

$$\overline{\boldsymbol{K}^{inv}} = \kappa^{inv} \sum_{p \in P} \boldsymbol{\delta}_p^{sea} \cdot \overline{\boldsymbol{\tau}_p^{sail}} \tag{47}$$

$$\overline{\boldsymbol{\Pi}} = \left[\overline{R} - \left(\overline{K^{hand}} + \overline{\boldsymbol{K}^{late}} + \overline{\boldsymbol{K}^{fuel}} + \overline{K^{oper}} + \overline{K^{char}} + \overline{\boldsymbol{K}^{inv}} \right) \right] \tag{48}$$

4.2.2. Handling Rate Adjustment

The base mathematical model for the ship schedule recovery with handling rate adjustment (**SSR-HRA**) can be formulated using the objective function (49) and constraints (29)–(34), (36)–(41), (43)–(47), and (50)–(54). Similar to the **SSR-SSA** mathematical model, the **SSR-HRA** objective function (49) aims to minimize the total loss of profit that will be endured by the shipping line as a result of disruptions at the considered shipping route. The total profit loss is estimated as a difference between the total profit that was expected to be accumulated by the shipping line for the original ship schedule (Π^0—USD) and the total profit that will be accumulated by the shipping line for the recovered schedule of ships ($\overline{\boldsymbol{\Pi}}$—USD).

$$min \left[\Pi^0 - \overline{\boldsymbol{\Pi}} \right] \tag{49}$$

Constraints (50) compute the recovered sailing speed of ships on each voyage leg, considering the expected change in sailing speed of ships due to a disruption. Constraints (51) assure that only one handling rate will be chosen at each port to serve the arriving ships. Constraints (52) calculate the recovered handling time of ships at ports, considering the expected duration of disruptions and potential handling rate adjustment to compensate for the effects of disruptions. Constraints (53) estimate the total cost associated with container handling at ports for the recovered schedule of ships, considering potential handling rate adjustments at ports. Constraints (54) calculate the total profit that will be accumulated by the shipping line for the recovered schedule of ships, considering potential handling rate adjustments at ports.

$$\overline{\boldsymbol{s}_p} \leq s_p + \widetilde{\boldsymbol{\sigma}_p^{d-sea}} \cdot \widetilde{\boldsymbol{z}_p^{sea}} \ \forall p \in P \tag{50}$$

$$\sum_{h \in H_p} \boldsymbol{x}_{ph} = 1 \ \forall p \in P \tag{51}$$

$$\overline{\boldsymbol{\tau}_p^{hand}} = \sum_{h \in H_p} \left(\frac{\overline{\delta_p^{port}}}{\chi_{ph}} \right) \cdot \boldsymbol{x}_{ph} + \widetilde{\boldsymbol{\tau}_p^{d-port}} \cdot \widetilde{\boldsymbol{z}_p^{port}} \ \forall p \in P \tag{52}$$

$$\overline{\boldsymbol{K}^{hand}} = \sum_{p \in P} \sum_{h \in H_p} \kappa_{ph}^{hand} \cdot \boldsymbol{x}_{ph} \cdot \overline{\delta_p^{port}} \tag{53}$$

$$\overline{\boldsymbol{\Pi}} = \left[\overline{R} - \left(\overline{\boldsymbol{K}^{hand}} + \overline{\boldsymbol{K}^{late}} + \overline{\boldsymbol{K}^{fuel}} + \overline{K^{oper}} + \overline{K^{char}} + \overline{\boldsymbol{K}^{inv}} \right) \right] \tag{54}$$

4.2.3. Port Skipping

The base mathematical model for the ship schedule recovery with port skipping (**SSR-PS**) can be formulated using the objective function (55) and constraints (29)–(34), (36)–(40), (43)–(47), and (56)–(62). Similar to the **SSR-SSA** mathematical model, the **SSR-PS** objective function (55) aims to minimize the total loss of profit that will be endured by the shipping line as a result of disruptions at the considered shipping route. The total profit loss is estimated as a difference between the total profit that was expected to be accumulated by the shipping line for the original ship schedule (Π^0—USD) and the total profit that will be accumulated by the shipping line for the recovered schedule of ships ($\overline{\boldsymbol{\Pi}}$—USD).

$$min\left[\Pi^0-\overline{\boldsymbol{\Pi}}\right] \tag{55}$$

Constraints (56) compute the recovered sailing speed of ships on each voyage leg, considering the expected change in sailing speed of ships due to a disruption. Constraints (57) assure that a port could be potentially skipped by the shipping line if and only if a disruption happened at that port. Constraints (58) assure that a port could be potentially skipped by the shipping line if and only if the port skipping strategy would be a feasible option for that port. Constraints (59) calculate the recovered handling time of ships at ports, considering the expected duration of disruptions and potential port skipping to compensate for the effects of disruptions. Constraints (60) estimate the total revenue that will be accumulated by the shipping line for the recovered schedule of ships, considering potential port skipping. Constraints (61) compute the total cost associated with container handling at ports for the recovered schedule of ships, considering potential port skipping. Constraints (62) calculate the total profit that will be accumulated by the shipping line for the recovered schedule of ships, considering potential port skipping.

$$\overline{\boldsymbol{s}_p}\leq s_p+\widetilde{\boldsymbol{\sigma}_p^{d-sea}}\cdot\widetilde{\boldsymbol{z}_p^{sea}}\;\forall p\in P \tag{56}$$

$$\boldsymbol{x}_p^{skip}\leq\widetilde{\boldsymbol{z}_p^{port}}\;\forall p\in P \tag{57}$$

$$\boldsymbol{x}_p^{skip}\leq z_p^{skip}\;\forall p\in P \tag{58}$$

$$\overline{\boldsymbol{\tau}_p^{hand}}=\left(\frac{\overline{\delta_p^{port}}}{\chi_p}+\widetilde{\boldsymbol{\tau}_p^{d-port}}\cdot\widetilde{\boldsymbol{z}_p^{port}}\right)\cdot\left(1-\boldsymbol{x}_p^{skip}\right)\;\forall p\in P \tag{59}$$

$$\overline{\boldsymbol{R}}=\sum_{p\in P}\kappa_p^{rev}\cdot\overline{\delta_p^{port}}\cdot\left(1-\boldsymbol{x}_p^{skip}\right) \tag{60}$$

$$\overline{\boldsymbol{K}^{hand}}=\sum_{p\in P}\kappa_p^{hand}\cdot\overline{\delta_p^{port}}+\sum_{p\in P}\left(\kappa_p^{skip}+\kappa_p^{mis}\cdot\overline{\delta_p^{port}}\right)\cdot\boldsymbol{x}_p^{skip} \tag{61}$$

$$\overline{\boldsymbol{\Pi}}=\left[\overline{\boldsymbol{R}}-\left(\overline{\boldsymbol{K}^{hand}}+\overline{\boldsymbol{K}^{late}}+\overline{\boldsymbol{K}^{fuel}}+\overline{K^{oper}}+\overline{K^{char}}+\overline{\boldsymbol{K}^{inv}}\right)\right] \tag{62}$$

4.2.4. Port Skipping and Container Diversion

The base mathematical model for the ship schedule recovery with port skipping and container diversion (**SSR-PSCD**) can be formulated using the objective function (63) and constraints (29)–(34), (36)–(40), (43)–(47), (56)–(58), and (64)–(74). Similar to the **SSR-SSA** mathematical model, the **SSR-PSCD** objective function (63) aims to minimize the total loss of profit that will be endured by the shipping line as a result of disruptions on the considered shipping route. The total profit loss is estimated as a difference between the total profit that was expected to be accumulated by the shipping line for the original ship schedule (Π^0—USD) and the total profit that will be accumulated by the shipping line for the recovered schedule of ships ($\overline{\boldsymbol{\Pi}}$—USD).

$$min\left[\Pi^0-\overline{\boldsymbol{\Pi}}\right] \tag{63}$$

Constraints (64) assure that containers could be diverted to alternative ports only from the skipped ports for the considered shipping route. Constraints (65) assure that containers could be diverted from a given port to an alternative port if and only if such a diversion option is feasible. Constraints (66) determine the ports that will handle diverted containers. Constraints (67) compute the number of containers diverted from a given port to an alternative port. Constraints (68) assure that the available container terminal capacity at the alternative port is sufficient for accommodating the containers diverted. Constraints (69) assure that the available inland transport capacity at the alternative port is sufficient for accommodating the containers diverted. Constraints (70) calculate the recovered handling time of ships at ports, considering the expected duration of disruptions and potential port skipping with container diversion to compensate for the effects of disruptions. Constraints (71) estimate the total revenue that will be accumulated by the shipping line for the recovered schedule of ships, considering potential port skipping and container diversion. Constraints (72) compute the total cost associated with container handling at ports for the recovered schedule of ships, considering potential port skipping and container diversion. Constraints (73) calculate the total cost associated with container diversion for the recovered schedule of ships. Constraints (74) calculate the total profit that will be accumulated by the shipping line for the recovered schedule of ships, considering potential port skipping and container diversion.

$$\boldsymbol{x}_{pp^*}^{div} \leq \boldsymbol{x}_p^{skip} \ \forall p, p^* \in P, p \neq p^* \tag{64}$$

$$\boldsymbol{x}_{pp^*}^{div} \leq z_{pp^*}^{div} \ \forall p, p^* \in P, p \neq p^* \tag{65}$$

$$\boldsymbol{x}_{p^*}^{dd} \leq \sum_{p \in P: p \neq p^*} \boldsymbol{x}_{pp^*}^{div} \ \forall p^* \in P \tag{66}$$

$$\boldsymbol{\delta}_{pp^*}^{div} = \overline{\delta_p^{port}} \cdot \boldsymbol{x}_{pp^*}^{div} \ \forall p, p^* \in P, p \neq p^* \tag{67}$$

$$\sum_{p \in P: p \neq p^*} \boldsymbol{\delta}_{pp^*}^{div} \leq \delta_{p^*}^{term} \cdot x_{p^*}^{dd} \ \forall p^* \in P \tag{68}$$

$$\sum_{p \in P: p \neq p^*} \boldsymbol{\delta}_{pp^*}^{div} \leq \delta_{p^*}^{land} \cdot \boldsymbol{x}_{p^*}^{dd} \ \forall p^* \in P \tag{69}$$

$$\overline{\boldsymbol{\tau}_{p^*}^{hand}} = \left[\frac{\left(\overline{\delta_{p^*}^{port}} + \sum_{p \in P: p \neq p^*} \boldsymbol{\delta}_{pp^*}^{div} \right)}{\chi_{p^*}} + \widetilde{\boldsymbol{\tau}_{p^*}^{d-port}} \cdot \widetilde{\boldsymbol{z}_{p^*}^{port}} \right] \cdot \left(1 - \boldsymbol{x}_{p^*}^{skip} \right) \ \forall p^* \in P \tag{70}$$

$$\overline{\boldsymbol{R}} = \sum_{p \in P} \kappa_p^{rev} \cdot \overline{\delta_p^{port}} \cdot \left(1 - \boldsymbol{x}_p^{skip} \right) + \sum_{p \in P} \sum_{p^* \in P} \kappa_p^{rev} \cdot \boldsymbol{d}_{pp^*}^{div} \tag{71}$$

$$\overline{\boldsymbol{K}^{hand}} = \sum_{p \in P} \kappa_p^{hand} \cdot \overline{\delta_p^{port}} + \sum_{p \in P} \left(\kappa_p^{skip} + \kappa_p^{mis} \cdot \overline{\delta_p^{port}} \right) \cdot \boldsymbol{x}_p^{skip} \tag{72}$$

$$\overline{\boldsymbol{K}^{div}} = \sum_{p \in P} \sum_{p^* \in P} \left(\kappa_{pp^*}^{d-term} + \kappa_{pp^*}^{d-land} \right) \cdot \boldsymbol{d}_{pp^*}^{div} \tag{73}$$

$$\overline{\boldsymbol{\Pi}} = \left[\overline{\boldsymbol{R}} - \left(\overline{\boldsymbol{K}^{hand}} + \overline{\boldsymbol{K}^{late}} + \overline{\boldsymbol{K}^{fuel}} + \overline{K^{oper}} + \overline{K^{char}} + \overline{\boldsymbol{K}^{inv}} + \overline{\boldsymbol{K}^{div}} \right) \right] \tag{74}$$

4.3. Review of the Relevant Studies

The impacts of diverse disruptions in the port network were analyzed by Paul and Maloni [100], and a real-time analysis was undertaken to adapt to dynamically updated port operations. To reduce port and inventory expenses, the network overall capacity was optimized while taking into account the ocean and inland transit operations. The suggested decision support system could dynamically analyze cargo processing time and port capacity while constantly updating the algorithm using regression-based parametric meta-models. Jones et al. [101] created a modeling tool that could be used to simulate container movements in the USA (both imports and exports) under various disruptive scenarios, such as lengthy delays caused by security checks and port disruptions. The system for import/export routing and recovery analysis (SIERRA) development model simulated container movements between 46 nations and the USA. The model sought to reduce total transportation costs. A series of case studies were provided for a number of disruptive scenarios. The developed methodology was found to be efficient and might serve as a useful planning tool for the stakeholders.

Brouer et al. [99] suggested an optimization-based vessel schedule recovery problem (VSRP). The article showed that the planned VSRP is nondeterministic polynomial time hard (NP-hard). The study investigated four schedule recovery options: (a) adjusting the ship's sailing speed; (b) integrating sailing and port times; (c) skipping a port where a disruptive incident occurred; and (d) modifying the order of port visits. The model's performance was evaluated by applying numerous recovery scenarios to four real-life situations using an MIP solver, CPLEX. When compared to real-world recovery strategies, the proposed model was able to provide comparable or even superior solution quality. Li et al. [102] developed an operational recovery approach while taking uncertainty factors into account. Port swapping and port skipping were considered in a dynamic programming framework for major disruptions with longer delays. However, if the disruption was minor, the problem was formulated using nonlinear programming, where the only operational strategy taken was speeding up. Computational experiments were carried out to demonstrate the efficacy of the solution methodology, and the relative errors due to discretizing time units were calculated.

Qi [103] summarized the liner shipping disruption management problem. In the study, two models for recovering ship schedules were presented. The first model was designed to recover a single ship's schedule, whereas the second model was designed to recover the schedules of multiple ships. The goal was to reduce the total cost of fuel and the total cost of a late ship arrival to a minimum. The following operational actions were considered for ship schedule recovery: (a) adjusting the vessel's sailing speed; (b) port skipping; and (c) port switching. A solution method based on dynamic programming was then proposed. Fischer et al. [104] focused on dealing with ship fleet deployment disruptions in roll-on roll-off liner shipping. The objective was to minimize the entire route service cost, which included total ship operational costs, total fuel consumption costs, total delay costs, total chartering costs, and total costs due to non-provided service. The following disruption methods were proposed: (1) sailing time increase; (2) early arrival awards; and (3) penalization of risky voyage start timings. As a part of the research, a rolling horizon heuristic algorithm was developed for solving the mathematical model. According to the findings, an inclusion of robustness might significantly cut down shipping costs as well as the associated voyage delays.

Li et al. [9] were the first to suggest a real-time schedule recovery policy that took into consideration regular and irregular uncertainties. The recovery model was designed as a multi-stage stochastic control problem to minimize the delay penalty and fuel cost. Using the backward value iteration, an optimal control policy was found. The optimal control policy attributes were established for both types of uncertainty with and without the earliest handling time constraint. Despite the superiority of the suggested real-time schedule recovery policy in computation, calculating the distribution of disruption events for a given planning horizon in practice still remains challenging. The automatic identification system (AIS) data could be used for planning liner shipping operations. Cheraghchi et al. [94] adopted the AIS data to mine and aggregate ship speeds. A speed-based VSRP was developed to minimize the ship schedule disruption. A multi-objective optimization problem was presented, and Pareto-optimal solutions were found using metaheuristic optimization methods. The three objectives of the study were minimizing the overall delays, reducing financial losses, and increasing the average speed conformity with historical values. The study used three evolutionary multi-objective optimizers (EMOO) to find Pareto-optimal solutions.

Ship schedule recovery and ship delays were the focus of the study by Hasheminia and Jiang [105]. Throughout the research, logistic and probit regression models were utilized to determine whether ship delays were random. The data obtained showed that a ship was less likely to be delayed at the terminal if more activities were scheduled in a short period of time (i.e., up to 3 days) after the ship berthing time window. The study also found that larger cargo ships had a lower chance of terminal delays. Smaller ports with less handling capacity face more uncertainty. The authors emphasized that increasing sailing speed is frequently seen as an unfavorable recovery approach due to significant increases in fuel costs. Liner shipping companies use various techniques to recover from disruptions, such as speeding up the ship to arrive at ports within specific time frames. However, increasing the ship's speed will cause a higher fuel cost, resulting in conflicting objectives. Cheraghchi et al. [106] proposed a multi-objective optimization problem (and corresponding multi-objective evolutionary algorithms) to address these conflicts. As a result, the calculated Pareto set was used to generate ship route-based speed profiles, allowing the stakeholder to make a flexible tradeoff between the total delay and financial losses. Furthermore, the results of the experiments conducted demonstrated the superiority of the NSGA-II metaheuristic.

Emission control areas, often referred to as "ECAs", have been established by the International Maritime Organization (IMO), which restricts the types of fuel that ships can use in ECAs and the amounts of emissions they can produce. These IMO regulations complicate the VSRP and were not considered in previous studies. Abioye et al. [107] developed a new mixed-integer nonlinear mathematical model to reduce financial losses for ships passing through emission control zones. The piecewise linear approximation was applied to the mathematical model, and the linearized model was solved by CPLEX. Port skipping and ship speed adjustments were considered as recovery options. Numerical experiments demonstrated that the suggested methodology could reduce the total loss while increasing energy efficiency and environmental sustainability. Mulder and Dekker [108] proposed a framework for determining optimal recovery policies and buffer allocations. Three recovery actions were considered: increasing sailing speed, skipping ports, and taking extreme measures (e.g., a "cut-and-go" action at ports). A mixed-integer programming model and a Markov decision process were used in the study. Due to the commercial solver's runtime limitations and the dimensionality curse that could occur in larger problems, four various heuristics were used to solve the problem in a limited time frame. The findings indicated that optimizing buffer time allocation reduced the costs by 28.9%.

Shipping companies use buffer time and speed adjustments to ensure that their timetables are reliable despite delays. Mulder et al. [109] developed a method that combined timetable planning and execution. The execution of the timetable was modeled using a stochastic dynamic program (SDP). Two options for recovery were considered: (1) increasing sailing speed; and (2) extreme recovery action. Given the need for efficient timetable execution, the study's approach sought SDPs with the lowest average long-term costs. A case study was provided based on the Maersk data. When compared to the current timetable, the ideal timetable saved between $4 million and $10 million per route each year. To address the VSRP, Xing and Wang [110] employed disruption management to balance service requirements and recovery costs. The study used three schedule recovery strategies: (1) speeding up and reducing port time; (2) swapping port calls; and (3) skipping a port call. According to the potential impact on customers, the priority of the recovery option tiers decreased sequentially. The study presented a service–cost balance model, which was classified as an MINLP model. The container flow recovery problem (CFRP) was also included in the mathematical model, with the assumption that containers could be moved to the next port call if a given port was skipped. No previous research integrated the VSRP and CFRP. The model was solved using LINGO. The optimal solution was found through computational studies, and the model was solved in minutes for a real-life scenario.

The granulated speed-based vessel schedule recovery problem (G-S-VSRP) is considered a big-data-enabled VSRP. The AIS data can be used to create a multi-objective optimization problem by geo-hashing the route between the ports. The G-S-VSRP aimed to reduce delays and financial losses while increasing speed conformity with historical navigational patterns. Geo-hash mining could analyze thousands of speed variables in the G-S-VSRP, creating a large-scale optimization problem. Traditional multi-objective evolutionary algorithms (MOEAs) would be unable to keep up with the problem's complexity. A divide-and-conquer method was used by Cheraghchi et al. [111] to improve the MOEA's performance in large-scale optimization problems. As a result of the research, a novel distributed multiplicative cooperative co-evolutionary algorithm was created. Abioye et al. [112] presented a VSRP that, unlike previous models, took into account various types of recovery actions, such as port skipping with/without container diversion, sailing speed adjustment, and handling rate adjustment. The BARON solver was used to solve the given nonlinear mathematical VSRP model. Several numerical experiments with various disruption events were conducted for the Middle East/Pakistan/India-West Mediterranean route. The results of the analysis provided liner shipping companies with managerial insights into designing more efficient ship schedule recovery plans.

De et al. [113] proposed a novel mathematical model to maximize the overall profit while addressing bunkering port selection, ship scheduling decisions, container operations, and determining the amount of oil to be bunkered at each port. To deal with weather-related delays, various recovery strategies, such as re-routing the ship and port swapping, were considered. The impact of fuel prices and the carbon tax on shipping operations was investigated in terms of the overall operating costs. The study provided important policy insights for shipping company executives in terms of having alternate ship route options in the event of normal or disrupted scenarios. Based on the study by Du et al. [114], a tactical liner shipping schedule design problem was examined under sail and port time uncertainty. Ships could lose speed due to weather conditions, delaying their scheduled arrival times. As an alternative, increasing the ship's speed-adjustment capability, while increasing fuel consumption, could reduce compensation for late arrivals. The study developed a machine learning-based model to address the above-mentioned constraints on speed adjustment measures. A machine learning-based methodology included speed adjustment, reinforcement learning, and neural network training. The effectiveness of machine learning approaches in shipping optimization was demonstrated by numerical studies, which validated the findings and provided a set of managerial insights.

4.4. Literature Summary and Research Gaps

4.4.1. Summary of Findings

A detailed summary of the reviewed studies on ship schedule recovery is presented in Table 2 focusing on the following information: (1) authors; (2) sailing speed assumptions; (3) port time assumptions; (4) objective function adopted; (5) components of the objective function adopted; (6) recovery strategies considered; (7) solution approach deployed; and (8) particular notes along with important study considerations. Furthermore, Figure 8 provides a distribution of the reviewed studies by model objective, objective components, recovery strategies, and solution approach. After a thorough review of the literature on ship schedule recovery, it can be concluded that the majority of studies assumed the ship sailing speed to be variable (a total of 94.4%). The study by Paul and Maloni [100] mostly focused on modeling disruptions at ports and did not explicitly consider sailing speed adjustment. On the other hand, 66.7% of studies modeled variable port times (see Table 2).

Table 2. Summary of the reviewed studies on ship schedule recovery.

a/a	Authors	Sailing Speed	Port Time	Objective	Objective Components	Recovery Strategies	Solution Approach	Notes/Important Considerations
1	Paul and Maloni (2010) [100]	F	V	Total route service cost minimization	MSC; TFC; TOC; TPC	Ship re-routing	Heuristic	Disruptive event modeling at ports
2	Jones et al. (2011) [101]	V	V	Total cost minimization	MSC	Ship re-routing; Port skipping; Port skipping with container diversion	Heuristic	Proposed a decision support tool to emulate disruptions affecting the USA freight intermodal network
3	Brouer et al. (2013) [99]	V	V	Total route service cost minimization	MSC; TFC; TOC; TPC; TVC	Speed adjustment; Port skipping; Port swapping	CPLEX	Proving the VSRP to be NP-complete
4	Li et al. (2015) [102]	V	V	Total route service cost minimization	TFC; TVC	Speed adjustment; Port skipping; Port swapping	Dynamic Programming	Finding a suitable delay penalty function
5	Qi (2015) [103]	V	V	Total route service cost minimization	TFC; TVC	Speed adjustment; Port skipping; Port swapping	Dynamic Programming	Introduction of two major models, one for a single ship and another one for multiple ships in one network
6	Fischer et al. (2016) [104]	V	F	Total route service cost minimization	MSC; TFC; TOC; TVC	Speed adjustment; Rewards for early arrivals; Penalization of risky voyage start times	Heuristic	Addressing disruptions in the fleet deployment for roll-on roll-off shipping
7	Li et al. (2016) [9]	V	V	Total route service cost minimization	MSC; TFC; TPC; TVC	Speed adjustment; Handling rate adjustment; Port skipping	Dynamic Programming	Considering both regular and unexpected uncertain events
8	Cheraghchi et al. (2017) [94]	V	F	Total monetary loss minimization; Total delay minimization; Average speed compliance maximization	MSC; TFC; TVC	Speed adjustment	Metaheuristics	Ship schedule delays were analyzed using the historical AIS data
9	Hasheminia and Jiang (2017) [105]	V	U	Total delay minimization	N/A	N/A	Analytical Method	Ships with a larger number of containers had a lower risk of delays at the terminal
10	Cheraghchi et al. (2018) [106]	V	F	Total monetary loss minimization; Total delay minimization	TFC; TVC	Speed adjustment	Metaheuristics	Problem evaluation in three scenarios (i.e., scalability analysis, ship steaming policies, and voyage distance analysis)

Table 2. *Cont.*

a/a	Authors	Sailing Speed	Port Time	Objective	Objective Components	Recovery Strategies	Solution Approach	Notes/Important Considerations
11	Abioye et al. (2019) [107]	V	V	Total monetary loss minimization	REV; TFC; TIC; TOC; TPC; TVC	Speed adjustment; Port skipping	CPLEX	Capturing enforced regulations within emission control areas
12	Mudler and Dekker (2019) [108]	V	V	Total route service cost minimization	TFC; TVC	Speed adjustment; Port skipping; Extreme recovery actions	Heuristic	Allocation of buffer times
13	Mulder et al. (2019) [109]	V	V	Total route service cost minimization	MSC; TFC; TVC	Speed adjustment; Extreme recovery actions	Iterative Optimization Algorithm	Proposing a method for the integrated development of ship timetables; allocation of buffer times
14	Xing and Wang (2019) [110]	V	V	Total route service cost minimization	MSC; TFC; TPC; TVC	Speed adjustment; Handling rate adjustment; Port swapping; Port skipping without container diversion; Port skipping with container diversion	LINGO	The proposed ship schedule recovery options were categorized into three tiers
15	Cheraghchi et al. (2020) [111]	V	F	Total monetary loss minimization; Total delay minimization; Average speed compliance maximization	MSC; TFC; TVC	Speed adjustment	Metaheuristics	A multi-objective optimization model was developed using the Automatic Identification System (AIS) data
16	Abioye et al. (2021) [112]	V	V	Total monetary loss minimization	MSC; REV; TFC; TOC; TPC; TVC	Speed adjustment; Handling rate adjustment; Port skipping without container diversion; Port skipping with container diversion	BARON	Capturing various realistic scenarios of disruptions
17	De et al. (2021) [113]	V	V	Total profit maximization	REV; TEC; TFC; TPC	Ship re-routing; Port swapping	Heuristic	Deciding on ship scheduling actions and container operations; deciding on the location and amount of marine diesel oil and heavy fuel oil to be bunkered
18	Du et al. (2021) [114]	V	U	Total route service cost minimization	TFC; TOC; TVC	Speed adjustment	Heuristic	Development of a machine learning-based model

Notes: ***Sailing Speed and Port Time*** [V—Variable; F—Fixed; U—Uncertain]; ***Objective Components*** [MSC—Miscellaneous Costs; REV—Total Revenue; TEC—Total Ship Emission Cost; TFC—Total Fuel Consumption Cost; TIC—Total Container Inventory Cost; TOC—Total Ship Operational Cost; TPC—Total Port Handling Cost; TVC—Total Cost Associated with Violation of Port Time Windows].

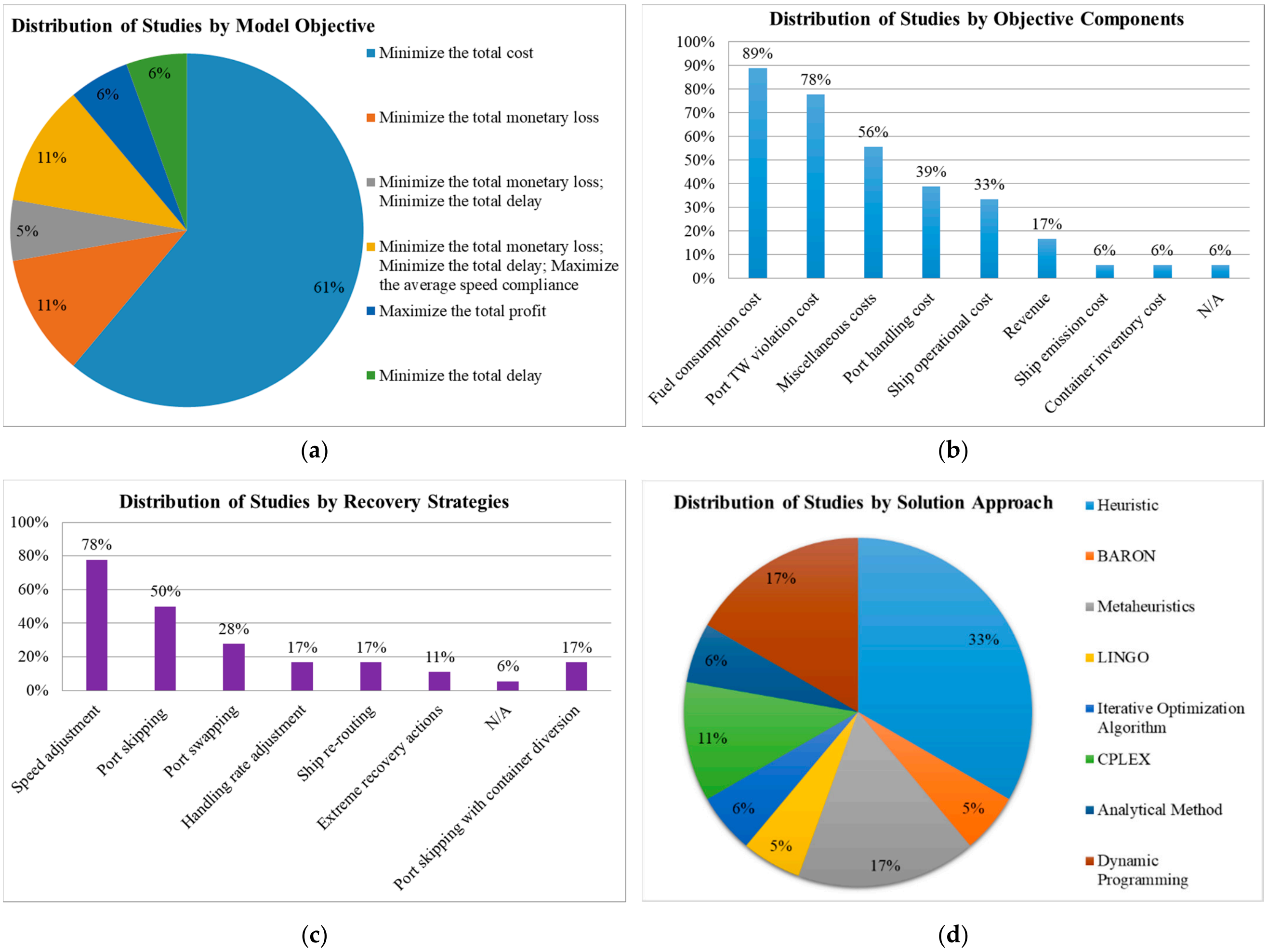


Figure 8. Distribution of the reviewed studies on ship schedule recovery by various attributes: (**a**) model objective; (**b**) objective components; (**c**) recovery strategies; and (**d**) solution approach.

As for the objective functions adopted, the majority of studies (more than 60%) aimed to minimize the total cost of route service, mainly considering fuel consumption cost, port TW violation cost, and port handling cost (see Figure 8). A significant portion of the mathematical models included miscellaneous cost components (e.g., costs incurred due to container diversion, costs due to misconnected cargo as a result of port skipping, costs due to accelerated ship handling at ports). Only one study focused on the total profit maximization [113]. Hasheminia and Jiang [105] investigated the effects of different factors on delays at marine container terminals, aiming to ensure the timely service of ships.

The analysis of the reviewed studies also shows that single-objective mathematical formulations were common (see Table 2). Only Cheraghchi et al. [94], Cheraghchi et al. [106], and Cheraghchi et al. [111] presented multi-objective mathematical formulations. In particular, the studies by Cheraghchi et al. [94] and Cheraghchi et al. [111] aimed to minimize the total monetary losses, minimize the total delay, and maximize the average speed compliance. On the other hand, Cheraghchi et al. [106] presented a bi-objective mathematical model, where the first objective function minimized the total monetary losses, whereas the second objective aimed to minimize the total delay. Sailing speed adjustment and port skipping without container diversion were found to be the most common recovery strategies that were used by the reviewed studies. Extreme recovery actions (e.g., “cut-and-go” when a ship can leave a given port without completing its service) were considered only by two studies, as these actions are not very common in practice. As for the solution methods adopted, heuristics and metaheuristics were found to be the most popular methods for the studies on ship schedule recovery. Furthermore, a significant number of research efforts deployed exact optimization solvers (e.g., CPLEX, LINGO, and BARON).

4.4.2. Limitations and Future Research Needs

The research gaps and a number of shortcomings in the existing studies on ship schedule recovery have been identified. These shortcomings and the future research that is required to bridge these gaps are as follows:

- ➢ Ship schedule recovery is associated with conflicting decisions. In particular, sailing speed adjustment may allow for partially compensating delays during the voyage and maintaining adequate service levels for customers. However, such a recovery option will increase the amount of required fuel and fuel costs. There is a lack of multi-objective mathematical formulations for ship schedule recovery that are able to assist with the analysis of conflicting objectives [94,106,111]. Future research should focus more on multi-objective ship schedule recovery.
- ➢ Future studies should concentrate on the development of innovative forecasting methods that could predict the occurrence of disruptive events and their duration [110]. The outcomes from these methods could be further used by shipping lines in the selection of the appropriate recovery strategies and offset the effects of disruptive events.
- ➢ The shipping industry has been facing many challenges in recent years (e.g., COVID-19), and the cost of ship schedule recovery would add additional pressure on shipping lines. Risk-sharing mechanisms between carriers and shippers should be investigated further in future studies to alleviate the pressure on shipping lines and enable them to maintain a high level of customer service [110].
- ➢ Sailing speed adjustment can serve as an effective recovery option but incurs additional fuel costs. The fuel consumption of ships depends on some other attributes as well, including previous maintenance activities, ship payload, ship age, and ship geometric characteristics [15,107]. Future research on ship schedule recovery should account for the aforementioned attributes and accurately quantify the amount of required fuel for the recovered ship schedules.
- ➢ Decentralized decision-making with several shipping lines should be studied more in depth. A freight forwarder, for example, may arrange transshipment between the ships of two different shipping lines. These two shipping lines would coordinate their ship recovery schedules for transshipment in an ideal world. Nevertheless, since each shipping line must minimize its cost function, centralized and optimized scheduling would be difficult to execute in practice. Game-theoretic models for ship schedule recovery in decentralized settings would be suitable in such scenarios [103].
- ➢ Sailing speed adjustment was identified as the most popular ship schedule recovery strategy. However, sailing speed adjustment alone may not be able to fully offset the effects of a disruptive event. Therefore, future studies should focus on the development of more advanced mathematical models and solution methods that consider a simultaneous implementation of various recovery strategies (e.g., sailing speed adjustment + port skipping or port swapping—[106]).
- ➢ Certain extreme ship schedule recovery options (e.g., "cut-and-go" when a ship can leave a given port without completing its service) should be better explored by future research efforts to determine the scenarios when these options might be viable and reduce potential monetary losses due to disruptive events.
- ➢ The effects of disruptions at ports and sea may influence not only shipping lines but other major supply chain players as well, including marine terminal operators, logistics companies, and inland operators [47]. Future mathematical models should evaluate various recovery strategies, considering the entire intermodal network effects—not just ship schedules.
- ➢ Drones have been widely used for monitoring various assets, including the assessment of infrastructure damages as a result of disruptive events [115–119]. The deployment of drones for the assessment of disruptive events in liner shipping operations should

be investigated as a part of future research. Drones can be used to accurately determine the effects of damages to the port infrastructure and the expected duration of port closures.

5. Concluding Remarks

Maritime transportation has been a popular mode of transportation (especially, for the transfer of bulk and containerized cargoes) but often faces different types of disruptions, such as port congestion, labor strikes, severe weather conditions, shipping container shortages, and customs delays. The outbreak of COVID-19 is recognized as a major disruptive event for liner shipping and maritime transportation, which resulted in the closure of certain marine terminals and substantial supply chain disruptions. A large number of studies were dedicated to the planning of different liner shipping operations. Furthermore, a number of survey studies were conducted in the past aiming to provide a holistic overview of the liner shipping literature. Nevertheless, there is still a lack of systematic literature surveys that specifically concentrate on uncertainties in liner shipping operations and ship schedule recovery. Therefore, the present research conducted a comprehensive up-to-date review of the liner shipping literature with a specific emphasis on uncertainties in liner shipping operations and ship schedule recovery. The collected studies were reviewed in a systematic way capturing the main assumptions regarding sailing speed and port time modeling, objective(s) considered, objective function components, uncertain elements, ship schedule recovery options, solution approaches, and specific considerations adopted. Moreover, supporting mathematical formulations were presented along with the major future research needs.

It was found that the reviewed studies mostly aimed to minimize the total cost of route service, primarily considering fuel consumption cost, ship operational cost, and port time window violation cost. A significant number of studies captured uncertainty in port handling time and ship sailing time. Single-objective mathematical formulations were common among the collected studies. A large variety of solution methods were presented for the considered decision problems related to uncertainties in liner shipping operations and ship schedule recovery, including heuristic methods, metaheuristic methods, and exact optimization methods (e.g., CPLEX, GUROBI, and BARON). Sailing speed adjustment and port skipping without container diversion were found to be the most common recovery strategies that were used by the reviewed studies. Extreme recovery actions (e.g., "cut-and-go" when a ship can leave a given port without completing its service) were considered only by a few studies. The outcomes from this research are expected to assist the relevant stakeholders involved in liner shipping operations with improvements in the reliability of their schedules and selection of the appropriate recovery options in response to major disruptive events.

There are several areas for extending the scope of this study that can be explored by future studies. First, a set of detailed interviews could be conducted with the relevant stakeholders involved in liner shipping operations to identify the best practices used to maintain schedule reliability and determine whether these practices receive sufficient attention in the literature. Second, a set of detailed interviews could be conducted with the marine terminal operators and inland operators to better understand how liner shipping disruptions influence terminal operations and identify the best mitigation strategies. Third, the future research needs, which were identified as a part of the performed literature survey, should be prioritized considering the input from the relevant stakeholders. Fourth, a new literature survey could be conducted to better understand the impacts of the COVID-19 pandemic on maritime supply chains. The identified insights could be further used to make maritime supply chains more resilient and be more prepared for the pandemics that may come in the following years.

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Appendix A. Notations Adopted in the Proposed Mathematical Formulations

Table A1. Definition of sets.

Set	Description of Sets	Remarks
$P = \{1, \ldots, n^1\}$	set of ports for the considered shipping route (ports)	All models
$H_p = \left\{1, \ldots, n_p^2\right\}, p \in P$	set of handling rates that can be requested by the shipping line at port p (handling rates)	**SSR-HRA**

Notes: **SSR-HRA**—ship schedule recovery with handling rate adjustment.

Table A2. Definition of decision variables.

Decision Variable	Description of Decision Variables	Remarks
$\boldsymbol{s}_p \in \mathbb{R}^+ \ \forall p \in P$	sailing speed of ships on voyage leg p (knots)	**SSP-U**
$\boldsymbol{q}^{tot} \in \mathbb{N}$	number of ships to be deployed (ships)	**SSP-U**
$\boldsymbol{\sigma}_p^{sea} \in \mathbb{R} \ \forall p \in P$	adjustment of ship sailing speed on voyage leg p (knots)	**SSR-SSA**
$\boldsymbol{x}_{ph} \in \mathbb{B} \ \forall p \in P, h \in H_p$	=1 if handling rate h will be used for ship service at port p (otherwise = 0)	**SSR-HRA**
$\boldsymbol{x}_p^{skip} \in \mathbb{B} \ \forall p \in P$	=1 if port p will be skipped by the shipping line (otherwise = 0)	**SSR-PS** and **SSR-PSCD**
$\boldsymbol{x}_{pp^*}^{div} \in \mathbb{B} \ \forall p, p^* \in P, p \neq p^*$	=1 if containers will be diverted from port p that experienced a disruption to alternative port p^*(otherwise = 0)	**SSR-PSCD**

Notes: **SSP-U**—ship scheduling problem with uncertainties; **SSR-SSA**—ship schedule recovery with sailing speed adjustment; **SSR-HRA**—ship schedule recovery with handling rate adjustment; **SSR-PS**—ship schedule recovery with port skipping; **SSR-PSCD**—ship schedule recovery with port skipping and container diversion.

Table A3. Definition of auxiliary variables.

Auxiliary Variable	Description of Auxiliary Variables	Remarks
$\boldsymbol{q}^{own} \in \mathbb{N}$	number of own ships to be deployed (ships)	**SSP-U**
$\boldsymbol{q}^{char} \in \mathbb{N}$	number of chartered ships to be deployed (ships)	**SSP-U**
$\boldsymbol{\tau}_p^{arr} \in \mathbb{R}^+ \ \forall p \in P$	arrival time of ships at port p (hours)	**SSP-U**
$\overline{\boldsymbol{\tau}_p^{arr}} \in \mathbb{R}^+ \ \forall p \in P$	recovered arrival time of ships at port p (hours)	**SSR**
$\overline{\boldsymbol{\tau}_p^{wait}} \in \mathbb{R}^+ \ \forall p \in P$	recovered waiting time of ships at port p (hours)	**SSR**
$\overline{\boldsymbol{\tau}_p^{hand}} \in \mathbb{R}^+ \ \forall p \in P$	recovered handling time of ships at port p (hours)	**SSR**
$\boldsymbol{\tau}_p^{dep} \in \mathbb{R}^+ \ \forall p \in P$	departure time of ships from port p (hours)	**SSP-U**

Table A3. *Cont.*

Auxiliary Variable	Description of Auxiliary Variables	Remarks
$\overline{\tau_p^{dep}} \in \mathbb{R}^+ \; \forall p \in P$	recovered departure time of ships from port p (hours)	**SSR**
$\overline{s_p} \in \mathbb{R}^+ \; \forall p \in P$	recovered sailing speed of ships on voyage leg p (knots)	**SSR**
$\tau_p^{sail} \in \mathbb{R}^+ \; \forall p \in P$	sailing time of ships on voyage leg p (hours)	**SSP-U**
$\overline{\tau_p^{sail}} \in \mathbb{R}^+ \; \forall p \in P$	recovered sailing time of ships on voyage leg p (hours)	**SSR**
$\tau_p^{late} \in \mathbb{R}^+ \; \forall p \in P$	late arrival hours of ships at port p (hours)	**SSP-U**
$\overline{\tau_p^{late}} \in \mathbb{R}^+ \; \forall p \in P$	recovered late arrival hours of ships at port p (hours)	**SSR**
$\overline{\tau^{stt}} \in \mathbb{R}^+$	turnaround time of ships for the recovered ship schedule (hours)	**SSR**
$\varphi_p \in \mathbb{R}^+ \; \forall p \in P$	consumption of fuel by the main engines of ships on voyage leg p (tons/nmi)	**SSP-U**
$\overline{\varphi_p} \in \mathbb{R}^+ \; \forall p \in P$	recovered consumption of fuel by the main engines of ships on voyage leg p (tons/nmi)	**SSR**
$\delta_p^{port} \in \mathbb{R}^+ \; \forall p \in P$	number of containers to be handled at port p (TEUs)	**SSP-U**
$\delta_p^{sea} \in \mathbb{R}^+ \; \forall p \in P$	number of containers to be carried on voyage leg p (TEUs)	All models
$x_p^{dd} \in \mathbb{B} \; \forall p \in P$	=1 if containers diverted from a port that experienced a disruption will be handled at alternative port p (otherwise = 0)	**SSR-PSCD**
$\delta_{pp^*}^{div} \in \mathbb{N} \; \forall p, p^* \in P, p \neq p^*$	number of containers diverted from port p that experienced a disruption to alternative port p^* (TEUs)	**SSR-PSCD**
$K^{hand} \in \mathbb{R}^+$	total cost associated with container handling at ports (USD)	**SSP-U**
$\overline{K^{hand}} \in \mathbb{R}^+$	total cost associated with container handling at ports for the recovered schedule of ships (USD)	**SSR**
$K^{late} \in \mathbb{R}^+$	total cost associated with late ship arrivals (USD)	**SSP-U**
$\overline{K^{late}} \in \mathbb{R}^+$	total cost associated with late ship arrivals for the recovered schedule of ships (USD)	**SSR**
$K^{fuel} \in \mathbb{R}^+$	total cost associated with fuel consumption (USD)	**SSP-U**
$\overline{K^{fuel}} \in \mathbb{R}^+$	total cost associated with fuel consumption for the recovered schedule of ships (USD)	**SSR**
$K^{oper} \in \mathbb{R}^+$	total cost associated with basic ship operations (USD)	**SSP-U**
$K^{char} \in \mathbb{R}^+$	total cost associated with chartering of ships (USD)	**SSP-U**
$K^{inv} \in \mathbb{R}^+$	total cost associated with container inventory (USD)	**SSP-U**
$\overline{K^{inv}} \in \mathbb{R}^+$	total cost associated with container inventory for the recovered schedule of ships (USD)	**SSR**
$\overline{K^{div}} \in \mathbb{R}^+$	total cost associated with container diversion for the recovered schedule of ships (USD)	**SSR-PSCD**
$R \in \mathbb{R}^+$	total revenue that will be accumulated by the shipping line (USD)	**SSP-U**
$\overline{R} \in \mathbb{R}^+$	total revenue that will be accumulated by the shipping line for the recovered schedule of ships (USD)	**SSR**
$\Pi \in \mathbb{R}^+$	total profit that will be accumulated by the shipping line (USD)	**SSP-U**
$\overline{\Pi} \in \mathbb{R}^+$	total profit that will be accumulated by the shipping line for the recovered schedule of ships (USD)	**SSR**

Notes: **SSP-U**—ship scheduling problem with uncertainties; **SSR**—ship schedule recovery models (i.e., **SSR-SSA** and **SSR-PS** and **SSR-PSCD** and **SSR-HRA**); **SSR-SSA**—ship schedule recovery with sailing speed adjustment; **SSR-HRA**—ship schedule recovery with handling rate adjustment; **SSR-PS**—ship schedule recovery with port skipping; **SSR-PSCD**—ship schedule recovery with port skipping and container diversion.

Table A4. Definition of parameters.

Parameter	Description of Parameters	Remarks
$\tau_p^{st} \in \mathbb{R}^+ \; \forall p \in P$	start of the arrival TW at port p (hours)	**SSR**
$\tau_p^{end} \in \mathbb{R}^+ \; \forall p \in P$	end of the arrival TW at port p (hours)	**SSP-U**
$\tau_p^{arr} \in \mathbb{R}^+ \; \forall p \in P$	arrival time of ships at port p for the original ship schedule (hours)	**SSR**
$\chi_p \in \mathbb{R}^+ \; \forall p \in P$	handling productivity for ship service at port p (TEU/hour)	**SSR**
$\chi_{ph} \in \mathbb{R}^+ \; \forall p \in P, h \in H_p$	handling productivity for ship service at port p when handling rate h is requested (TEU/hour)	**SSR-HRA**
$\phi \in \mathbb{N}$	frequency of port service for the considered shipping route (days)	All models
$q^{own-max} \in \mathbb{N}$	maximum number of own ships that could be deployed for the considered shipping route (ships)	**SSP-U**
$q^{char-max} \in \mathbb{N}$	maximum number of chartered ships that could be deployed for the considered shipping route (ships)	**SSP-U**
$\overline{q^{own}} \in \mathbb{N}$	number of own ships to be deployed for the original ship schedule (ships)	**SSR**
$\overline{q^{char}} \in \mathbb{N}$	number of chartered ships to be deployed for the original ship schedule (ships)	**SSR**
$\overline{\delta_p^{port}} \in \mathbb{R}^+ \; \forall p \in P$	number of containers to be handled at port p for the original ship schedule (TEUs)	**SSR**
$l_p \in \mathbb{R}^+ \; \forall p \in P$	length of voyage leg p for the considered shipping route (nmi)	All models
$\alpha, \gamma \in \mathbb{R}^+$	coefficients associated with the fuel consumption function	All models
$\omega \in \mathbb{R}^+$	average cargo weight within a standard TEU (tons)	All models
$\delta^{empty} \in \mathbb{R}^+$	weight of a ship without containers (tons)	All models
$\delta^{cap} \in \mathbb{R}^+$	maximum weight of containers that could be loaded on a ship (tons)	All models
$s^{max} \in \mathbb{R}^+$	maximum sailing speed that could be set for ships (knots)	**SSR**
$s^{min} \in \mathbb{R}^+$	minimum sailing speed that could be set for ships (knots)	**SSR**
$s_p \in \mathbb{R}^+ \; \forall p \in P$	sailing speed of ships on voyage leg p for the original ship schedule (knots)	**SSR**
$\widetilde{\boldsymbol{\tau}_p^{wait}} \in \mathbb{R}^+ \; \forall p \in P$	expected waiting time of ships at port p (hours)	**SSP-U**
$\widetilde{\boldsymbol{\tau}_p^{hand}} \in \mathbb{R}^+ \; \forall p \in P$	expected handling time of ships at port p (hours)	**SSP-U**
$\widetilde{\boldsymbol{\tau}_p^{d-port}} \in \mathbb{R}^+ \; \forall p \in P$	expected duration for a disruption at port p (hours)	**SSR**
$\widetilde{\boldsymbol{\sigma}_p^{d-sea}} \in \mathbb{R} \; \forall p \in P$	expected change in sailing speed of ships due to a disruption on voyage leg p (knots)	**SSR**
$\widetilde{\boldsymbol{z}_p^{port}} \in \mathbb{B} \; \forall p \in P$	=1 if a disruption happened at port p (otherwise = 0)	**SSR**
$\widetilde{\boldsymbol{z}_p^{sea}} \in \mathbb{B} \; \forall p \in P$	=1 if a disruption happened on voyage leg p (otherwise = 0)	**SSR**
$z_p^{skip} \in \mathbb{B} \; \forall p \in P$	=1 if the port skipping would be a feasible option for port p as a result of disruption occurrence (otherwise = 0)	**SSR-PS** and **SSR-PSCD**
$z_{pp^*}^{div} \in \mathbb{B} \; \forall p, p^* \in P, p \neq p^*$	=1 if containers can be potentially diverted from port p that experienced a disruption to alternative port p^* (otherwise = 0)	**SSR-PSCD**
$\delta_p^{term} \in \mathbb{R}^+ \; \forall p \in P$	available container terminal capacity for accommodating the containers diverted at port p (TEUs)	**SSR-PSCD**
$\delta_p^{land} \in \mathbb{R}^+ \; \forall p \in P$	available inland transport capacity for accommodating the containers diverted at port p (TEUs)	**SSR-PSCD**
$\kappa_p^{hand} \in \mathbb{R}^+ \; \forall p \in P$	unit cost associated with container handling at port p (USD/TEU)	**All models**
$\kappa_{ph}^{hand} \in \mathbb{R}^+ \; \forall p \in P, \; h \in H_p$	unit cost associated with container handling at port p when handling rate h is requested (USD/TEU)	**SSR-HRA**

Table A4. *Cont.*

Parameter	Description of Parameters	Remarks
$\kappa_p^{late} \in \mathbb{R}^+ \ \forall p \in P$	unit cost associated with late ship arrivals at port p (USD/hour)	All models
$\kappa^{fuel} \in \mathbb{R}^+$	unit cost associated with fuel consumption (USD/ton)	All models
$\kappa^{oper} \in \mathbb{R}^+$	unit cost associated with basic ship operations (USD/day)	All models
$\kappa^{char} \in \mathbb{R}^+$	unit cost associated with chartering of ships (USD/day)	All models
$\kappa^{inv} \in \mathbb{R}^+$	unit cost associated with container inventory (USD/TEU/hour)	All models
$\kappa_p^{rev} \in \mathbb{R}^+ \ \forall p \in P$	unit cost associated with transporting the cargo for the considered shipping route, i.e., freight rate (USD/TEU)	All models
$\kappa_p^{skip} \in \mathbb{R}^+ \ \forall p \in P$	cost associated with skipping port p for the considered shipping route (USD)	**SSR-PS** and **SSR-PSCD**
$\kappa_p^{mis} \in \mathbb{R}^+ \ \forall p \in P$	unit cost associated with misconnected cargo at port p for the considered shipping route (USD/TEU)	**SSR-PSCD**
$\kappa_{pp^*}^{d-term} \in \mathbb{R}^+ \ \forall p, p^* \in P$, $p \neq p^*$	unit cost associated with handling the containers diverted from port p that experienced a disruption at alternative port p^* (USD/TEU)	**SSR-PSCD**
$\kappa_{pp^*}^{d-land} \in \mathbb{R}^+ \ \forall p, p^* \in P$, $p \neq p^*$	unit cost associated with inland transport cost of the containers diverted from port p that experienced a disruption at alternative port p^* (USD/TEU)	**SSR-PSCD**
$\Pi^0 \in \mathbb{R}^+$	total profit that was expected to be accumulated by the shipping line for the original ship schedule (USD)	**SSR**
$\overline{K^{oper}} \in \mathbb{R}^+$	total cost associated with basic ship operations for the recovered schedule of ships (USD)	**SSR**
$\overline{K^{char}} \in \mathbb{R}^+$	total cost associated with chartering of ships for the recovered schedule of ships (USD)	**SSR**

Notes: **SSP-U**—ship scheduling problem with uncertainties; **SSR**—ship schedule recovery models (i.e., **SSR-SSA** and **SSR-PS** and **SSR-PSCD** and **SSR-HRA**); **SSR-SSA**—ship schedule recovery with sailing speed adjustment; **SSR-HRA**—ship schedule recovery with handling rate adjustment; **SSR-PS**—ship schedule recovery with port skipping; **SSR-PSCD**—ship schedule recovery with port skipping and container diversion.

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Vessel Deployment and De-Hubbing in Maritime Networks: A Case Study on Colombo Port and Its Feeder Market

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Abstract: Generally, vessels are deployed as hub-and-spoke networks to achieve high slot utilization and cost efficiency for shipping lines in global maritime container shipping networks. At the Port of Colombo, most transhipment containers originate from and are destined for Indian ports, the export/import container volume of which has been rapidly increasing, and Indian ports have been developed to accommodate vessel enlargement. In such circumstances, the partial or complete abandonment of a hub (Colombo port) in this region is expected, which is known as "de-hubbing." This study aims to clarify the impact of port developments and an increase in container cargo demand from the source country on maritime network selection from the perspective of shipping lines. We develop a mixed integer linear programming model to describe vessel deployment, including transhipment via the Colombo port and direct shipment in Indian ports. As a result of the analysis, the number of direct services to Indian ports is expected to increase when the cargo demand of Indian ports increases and the port development of Indian ports is conducted. The progress of the de-hubbing phenomenon decreases vessel size at Colombo port because the container demand at Indian ports is mostly satisfied by newly deployed trunk lines to Indian ports. This study suggests that if Colombo port expects to maintain its hub status, it is critical to consider various other incentives to attract and retain mainline carriers in addition to expanding its port infrastructure. Similarly, if India expects to receive direct calls from mainlines, it is important not only to develop their port infrastructure but also to increase their cargo demand.

Keywords: vessel deployment; de-hubbing; transhipment; port development; container demand

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1. Introduction

In maritime container shipping networks, vessels are mostly deployed as hub-and-spoke networks. When shipping lines design maritime networks, vessel deployment is optimized to maximize profits or minimize costs. Aggregating cargo in specific nodes, which is called a hub port in the maritime shipping network, is a vital factor in achieving high slot utilization and cost efficiency for shipping lines [1]. From the perspective of shippers, hub-and-spoke networks require additional navigation distance, time, and port charges compared to point-to-point networks, primarily because the cargo that originates in a spoke must be transported via a hub [2]. However, adopting a hub-and-spoke network is cost-efficient for shipping lines because the freight rate tends to be lower when economies of scale are achieved. Hub-and-spoke networks can connect origin and destination ports through fewer shipping services than point-to-point networks. Accordingly, the configuration of hub-and-spoke networks can reduce network construction costs—aggregation can yield economies of scale and density more easily [3]. However, larger vessels are not always economically effective in hub-and-spoke networks because economies of density may not always exist [4,5]. In such cases, hub-and-spoke networks can be less cost-effective than point-to-point networks in some conditions, particularly the cargo generation of source countries. From the perspective of port authorities, many ports are attempting to be hub ports to influence regional or international economic services [6,7] and establish direct links with large markets via trunk lines [8].

The Port of Colombo, located at the centre of the trunk sea route connecting Europe and Asia, is one of the largest ports in South Asia. In 2015, the ratio of transhipment containers in the port of Colombo was 77.1% on a Twenty-foot Equivalent Unit (TEU) basis [9]. In particular, the ratio of these transhipment containers originating from and destined for the ports of India accounts for more than 75%, which implies that Colombo Port is heavily dependent on Indian containers. When considering the Port of Colombo and its development opportunities, a few development projects are currently underway for adding new berths and terminals in the near future. Particular examples are the addition of the East container terminal, the establishment of a logistics center and a multi-model transport hub adjacent to the port premises, the proposed North port development project, etc. At the same time, the export/import container volume in India has been increasing with rapid economic growth, which would influence the design of the network [10]. As a source country, if an adequate cargo volume is collected from India to fill container vessels, shipping lines would deploy trunk lines for Indian ports instead of using Colombo port as a hub because shipping lines would benefit less from cargo aggregation to/from Indian ports at Colombo port. In addition, Indian ports will invest in accommodating vessel enlargement because some Indian ports do not have the capacity to accommodate large vessels. In these cases, the dominant carrier is expected to abandon a hub, either partially or completely, which is known as “de-hubbing” [11].

Several studies have been conducted on network design problems in maritime transport. For example, the significance of container demand for designing shipping networks where direct and transhipment routes are available is highlighted. Shipping lines provide direct services when they find direct shipping profitable [2]. Moreover, the demand for cargo volume influences the design of shipping networks [1]. The container vessel capacity has a significant influence on the design of maritime networks [12]. There is a tendency to apply hub-and-spoke networks when the capacity of the hub port increases [13]. In these existing works, port development and container demand in the source country would be a significant variable for network design in maritime container transport. However, to the best of our knowledge, no study has attempted to clarify the relationship between the port development and container demand of source countries and network selection. Therefore, this study aims to identify how port development and container demand in container-originated/destined countries impact the de-hubbing phenomenon from the perspective of shipping lines. The case study was conducted by considering India as the source country for container cargoes and Colombo port as a regional hub port. Owing to strong economic growth and a large population, Indian-originated container cargo is predicted to continuously increase in the future. Meanwhile, as a source country, Sri Lanka has a relatively smaller import/export container volume. Therefore, the case study considered India as the source country. In this study, mixed integer linear programming (MILP) was used to model the behavior of shipping lines, which can quantitatively represent the behavior of actual shipping lines. The decision variable of MILP is a binary variable that can represent ports of call of the liner services, using 0 or 1 within the sets of available ports. Once the model was developed, it was applied to multiple scenarios with a range of container demand values from the source country. The relationship between container demand and de-hubbing behavior of shipping lines was observed.

The remainder of this paper proceeds as follows: Section 2 reviews the existing literature on shipping network optimization and container cargo allocation. In Section 3, the model describing the shipping line behavior is developed using MILP. Section 4 addresses the actual situation of the study area, input values, and scenarios. Section 5 presents the results from simulating several scenarios using the developed model. Lastly, the main conclusions of the study and future research directions are presented in Section 6.

2. Literature Review

Several studies have analysed port choice behavior from the perspective of shipping lines (that is, vessel deployment) on several geographical scales for different shipping networks, such as hub-and-spoke and direct networks. Ji et al. (2015) [12] developed a routing optimization problem in hub-and-spoke networks using a genetic algorithm. The study targets involved the ports in the Pearl River Delta. The authors found several critical factors for the routing behavior of shipping lines, including the time deadline, container vessel capacity, and cargo handling capacity of each port. They use a genetic algorithm, but MILP is a widely used method for vessel deployment problems. This is because MILP has a high affinity with the disaggregated port call behavior of shipping lines. The following studies used MILP to forecast the vessel deployment and cargo volumes. Kim et al. (2019) [14] formulated a vessel deployment model using MILP in the ports in Southern Africa and analysed the market share of each liner service and found that sea freight rate affects routing problems in shipping networks. Mulder and Dekker (2014) [15] solved the combined fleet design problem, ship scheduling, and cargo routing problem as a network design problem. Zheng et al. (2015) [16] proposed a vessel deployment model using MILP with cost minimization in a network of 46 ports spread across Asia, Europe, and Oceania, including nine ports as hub ports with given demand. In these studies, a set of hub ports are predetermined, and the possibility of the deployment of large-scale vessels at non-hub ports were not considered. Agarwal and Ergun (2008) [17] and Brouer et al. (2013) [18] formulated a model for vessel deployment to maximize the profit of shipping lines. In these studies, the container demand was fixed, and the vessel deployment for the hub port was predetermined. Kawasaki et al. (2021) [19] considered the port choice model of shippers considering shipping lines' behavior. Research on container cargo allocation in global shipping networks has been conducted. Bell et al. (2008) [20] developed a container allocation model to minimize the cost of shipping lines by considering the container handling charges at ports, container rental costs, and the time value decay cost (that is, inventory cost) under the conditions of given routes, the size of vessels, and the cargo demand. Shibasaki and Kawasaki (2016) [21] developed a model to reproduce global container movements on the international maritime shipping network by applying a network equilibrium assignment method, which ensures cost equilibrium between competitive routes. Moreover, the authors also minimized the total cost of the shipping lines. Wang et al. (2015) [22] proposed a container allocation model that maximizes the profit of shipping lines by setting the freight rate. In the study, it was assumed that vessel sizes are given and container demand is dependent on the freight rate. These models assume that routes and ports called by shipping lines are fixed; however, the routes and ports served by shipping lines would change in accordance with cargo demand, as the present study considered.

Kim et al. (2018) [23] and Zheng and Dong (2016) [24] considered that routes and ports served by shipping lines are changed on the basis of the forecasted cargo demand in the ports. Furthermore, Kim et al. (2018) also developed a model for the route and port selection of shipping lines using MILP with several vessel size scenarios [23]. Zheng and Dong (2016) [24] examined ports along the Yangtze River and estimated the market share of transhipment containers at each hub port. The authors gradually changed the total demand of containers in this area to observe its effect on the volume of transhipment containers. Moreover, studies have been conducted on the selection between direct and transhipped shipments. Yeo et al. (2008) [25] stated that direct service to northern Chinese ports by major shipping lines has considerably reduced the transhipment container cargo at Busan Port. Kim et al. (2018) [23] estimated the market share of direct and transhipment cargo to/from Southern African ports using MILP when shipping lines used different vessel sizes. However, in their model, the trade between Southern African ports and Europe and

Southern African ports and Asia were formulated separately, and the direct route between Asia and Europe was not considered. Therefore, the model is not suitable for ports located on the key routes between Asia and Europe, such as the Port of Colombo in Sri Lanka, which is the main target of the case study.

Existing research on vessel deployment and container allocations from the perspective of shipping lines have been modelled using the MILP method with given conditions for container demand and shipping network. However, no research has analyzed the de-hubbing phenomenon with increasing cargo generation and attraction in source countries. In particular, there has been no research on vessel deployment in container transhipment trends at hub ports considering increases in future container cargo demand and port capacity. Besides, there is no model that evaluates transhipment volume at Colombo port considering the possibility of calling trunk lines between East Asia and Europe for Indian ports. In this study, we develop a model that enables trunk liner services to call for the Indian ports; subsequently, using the developed model, we examine the relationship between de-hubbing and cargo demand in a global shipping network.

3. Model Development

Similar to several previous studies, we applied MILP in this analysis to determine vessel deployment and port selection. We prepared the following two assumptions for the model. Firstly, shipping lines make their decisions on vessel deployment and port selection to maximize their profits. More specifically, it means that the route choices of shippers are not considered for the purpose of simplicity. Several researchers have adopted the assumption mentioned above to calculate the optimum shipping route served by shipping lines [17,18]. We also assume that shipping lines deploy the minimum number of vessels to maintain weekly service in each liner service for profit maximization. Secondly, the shipper pays the freight rate to the main shipping line for the liner service between the origin and destination ports. In other words, the main shipping line does not have to pay charges to the feeder shipping line. Instead, this feeder link cost (FLC) is included as the cost of the main shipping line for simplicity of calculation. The notations for the model are as follows.

In this study, the objective function of the shipping line is to maximize its profits in a week (Ps), for which it has three decision variables. Specifically, the shipping line decides on liner service (r) and vessel type (a) as network information, as well as container cargo volume (x). The shipping line chooses a service from a set of services (R) comprising combinations of target ports considered in the model. Vessel type refers to the deployment of vessel type to the service chosen from the set of vessel types (A). Determination of vessel type is accompanied by vessel size (s^a) and operation and fixed cost (OFC). One of the decision variables of the shipping line to decide the service and vessel type is a binary variable (y_r^a), which takes 1 if service r is served by vessel type a and 0 in the rest of the cases. The binary variable was grouped into vector $\boldsymbol{y}$. The other decision variables are cargo volume transported directly to the port pair (o,d) in service r $\left(\widetilde{x}_{o,d}^r\right)$ and cargo volume transported for the port pair (o,d) with transhipment in service r $\left(\hat{x}_{o,d}^r\right)$. The cargo volumes are grouped in a vector $\boldsymbol{x}$. Therefore, the shipping line decides the vectors $\boldsymbol{x}$ and $\boldsymbol{y}$ to maximize their profits.

Equation (1) shows the profit of the shipping line in a week. The first term consists of revenue, and five types of costs are shown in the second to sixth terms. The revenue of the shipping line (first term) is calculated by the product of container cargo volume $\left(\hat{X}_{od} \text{ and } \widetilde{X}_{od}\right)$ and freight rate ($\hat{F}_{od}$ and $\widetilde{F}_{od}$) obtained from the shipper. The second term in Equation (1) indicates the total bunker cost during the voyage. In this study, the number of deployed vessels in each service is to maintain weekly service. This indicates that the total distance of voyage of all deployed vessels per week equals the total distance of the liner service. Thus, we calculate the navigation time of all vessels per week by dividing the total navigation distance $(D_{r,i})$ between the target ports in the service by the navigation speed (v^a). Each vessel type a has a unique bunker cost (bc^a). The third term in Equation

(1) corresponds to the total loading and unloading costs (lc_p) in origin, destination, and hub port. The fourth term shows the total FLC related to the second assumption mentioned above. The costs of each FLC from ports o to d (fc_{od}) were calculated. The fifth term represents the total vessel cost, which indicates the OFC. The OFC was calculated, which is dependent on the number of vessels deployed in service $r(N_r)$ and each vessel cost (vc^a). The final term in Equation (1) indicates the total port charge, which is calculated as the sum of the port charge and pilotage fee at each port (pc_p).

$$\begin{aligned} Ps = & \sum_{(o,d)\in W} \left(\hat{X}_{od} \times \hat{F}_{od} + \widetilde{X}_{od} \times \widetilde{F}_{od}\right) - \sum_{r\in R}\sum_{a\in A}\sum_{i} bc^a \times y_r^a \times D_{r,i}/v^a \\ & - \sum_{(o,d)\epsilon W}\sum_{h}\left((lc_o + lc_d)\left(\widetilde{X}_{od} + \hat{X}_{od}\right) + \sum_{h}\hat{X}_{od} \times lc_h\right) - \sum_{(o,d)\in W}\hat{X}_{od} \times fc_{od} \\ & - \sum_{r\in R}\sum_{a\in A} N_r \times y_r^a \times vc^a - \sum_{a\in A}\sum_{r\in R}\sum_{p\in P} y_r^a \times z_r^p \times pc_p^a \end{aligned} \tag{1}$$

The optimization of the profit of shipping lines was formulated using the MILP model. Constraint 3 guarantees that each service can only have at most one vessel type. Constraint 4 defines container cargo that will not be transported on a service where there is no ship deployment. Constraints 5 and 6 are the sum of transhipment cargo and direct cargo in each service, which is equal to the total container cargo between the origin and destination for each direct and transhipment route. Constraint 7 illustrates that container cargo is transported in either direct or transhipment. The term Q_{od} represents the cargo demand from port o to port d, and the term θ is a coefficient for the scenario analysis of future cargo demand. Under the current conditions, θ was set as 1, and Constraints 8 and 9 indicate that cargo from origin to destination port must be transported in the service, including both the origin and destination. The term $w_{r,i}^{o,od}$ is a binary variable that takes the value of 1 if port o is *the i*-th port in service r; otherwise, it is 0. Constraint 10 defines the cargo volume on the vessel $(q_{r,i})$, and Constraint 11 is a constraint condition that ensures the cargo volume on the vessel is less than the capacity of the vessel. Constraint 12 defines the number of deployed vessels in each service based on the total travel time between the origin and destination ports. The total time is the sum of navigation time and the time spent at the port. The sum of the navigation time is calculated using the navigation distance and speed. Meanwhile, the time spent at the port is calculated by the average vessel turnaround time at port p (T_p). In this term, we introduce the binary variable Z_p^r, which takes the value of 1 if service r calls for port p; it is 0 otherwise. The value of 168 in the denominator is considered to convert from hours to weeks. We calculate the number of deployed vessels as the minimum number of vessels needed to maintain weekly service and satisfy the shipper's demand by Constraint 11 and 12. Constraint 13 denotes the term y_r^a as a binary variable. Constraint 14 ensures that the decision variables are non-negative.

$$\max Ps(\boldsymbol{x}, \boldsymbol{y}) \tag{2}$$

Subject to

$$\sum_{a\in A} y_r^a \le 1 \quad \forall r \in R \tag{3}$$

$$M \times y_r^a - \sum_{(o,d)\in W} (\widetilde{x}_{od}^r + \hat{x}_{od}^r) \ge 0 \quad \forall r \in R, \forall a \in A \tag{4}$$

$$\sum_{r\in R} \widetilde{x}_{od}^r = \widetilde{X}_{od} \quad \forall (o,d) \in W. \tag{5}$$

$$\sum_{r\in R} \hat{x}_{od}^r = \hat{X}_{od} \quad \forall (o,d) \in W \tag{6}$$

$$\widetilde{X}_{od} + \hat{X}_{od} = \theta \times Q_{od} \quad \forall (o,d) \in W \tag{7}$$

$$(\widetilde{x}^r_{od} + \hat{x}^r_{od}) - \sum_i M \times w^{o,od}_{r,i} \leq 0 \quad \forall r \in R, \forall (o,d) \in W \tag{8}$$

$$(\widetilde{x}^r_{od} + \hat{x}^r_{od}) - \sum_i M \times w^{d,od}_{r,i} \leq 0 \quad \forall r \in R, \forall (o,d) \in W \tag{9}$$

$$q_{r,i} = q_{r,i-1} + \sum_{(o,d) \in W} w^{o,od}_{r,i} \times \widetilde{x}^r_{od} + \sum_{(o,d) \in W} w^{o,od}_{r,i} \times \hat{x}^r_{od} - \sum_{(o,d) \in W} w^{d,od}_{r,i} \times \widetilde{x}^r_{od} - \sum_{(o,d) \in W} w^{d,od}_{r,i} \times \hat{x}^r_{od} \quad \forall i, \forall r \in R \tag{10}$$

$$q_{r,i} \leq \sum_{a \in A} y^a_r \times s_a \quad \forall i, \forall r \in R \tag{11}$$

$$N_r = min\left\{ n \in \mathbb{Z} \middle| n \geq \frac{\sum_i D_{r,i}/v^a + \sum_{p \in P} z^p_r \times T_p}{168} \right\} \quad \forall a \in A \tag{12}$$

$$y^a_r \in (0,1) \quad \forall r \in R, \forall a \in A \tag{13}$$

$$\widetilde{x}^r_{od} \geq 0, \hat{x}^r_{od} \geq 0 \quad \forall (o,d) \in W, \forall i, \forall r \in \mathrm{R} \tag{14}$$

4. Application to India and Colombo Ports

4.1. Study Area

This study focuses on container cargo flow between Europe, East Asia, the Colombo port, and the top 10 Indian ports in 2015 as a base case, since detailed transhipment data at Colombo port are available with 2015 as the latest data. However, our purpose can be sufficiently achieved by using the 2015 database as a base case. The Colombo port is located in Sri Lanka, an island at the centre of the trunk line between Europe and East Asia. It is a regional hub port for the Indian subcontinent (IS). Colombo port has advantages over Indian ports due to its bigger depth of port access channel, ability to handle larger container vessels, and its strategic location on major shipping routes. When considering the port location, although Colombo port has a strategic location with a short deviation from the main sea routes than Indian ports, there is a considerably high cost for the feeder link for connecting Indian feeder ports and Colombo port in a hub and spoke network. If Indian ports can accept larger container vessels by eliminating infrastructure limitations, shipping lines would eliminate the cost associated with feeder links. Therefore, some Indian ports, such as Mundra, Nhava Sheva, etc., are called directly by mainlines, especially in the last decade, possibly due to their infrastructure development and growth in total cargo volume originating from/to India.

Figure 1 and Table 1 illustrate the location and statistics of the Indian and Colombo ports, respectively. According to Table 1, the Colombo port shows the largest total cargo volume and frequency and highlights Colombo port's attractiveness as a hub. As shown in Table 1, ports in northwest India such as Nhava Sheva, Mundra, Pipavav, and Hazira have relatively small ratios of transhipment at Colombo. These ports are geographically farther than Colombo port and have direct shipment services to Europe and Asia. In particular, higher numbers of services are called for Nhava Sheva and Mundra because these ports have higher container volumes. Regarding Pipavav port, a higher frequency of direct shipments to East Asia is observed. Meanwhile, the transhipment ratios are high in ports where the frequency to Europe or East Asia is zero or one, such as Tuticorin and Krishnapatnam ports. In addition, ports geographically close to Colombo port, such as Cochin port, seem to have a higher transhipment ratio similar to that of Colombo port.

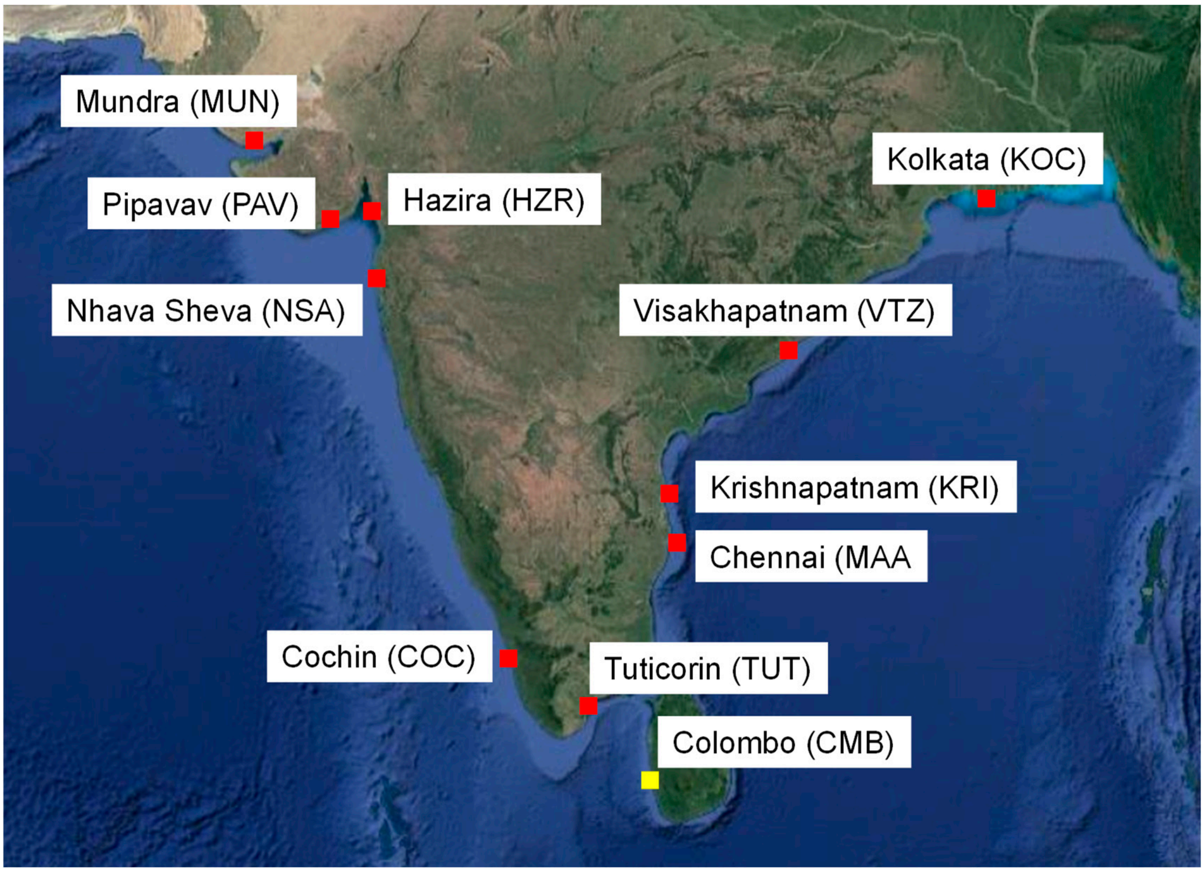

Figure 1. Location of Colombo and Indian ports. Source: Google map modified by authors.

Table 1. Statistics of Colombo and Indian ports in 2015.

Port	Cargo Volume		Frequency [Times/Week]	
	Total (Thousand TEU)	Ratio of T/S at Colombo (%)	Europe	East Asia
Colombo	5103	-	10	30
Nhava Sheva	4480	2.1	10	16
Mundra	2895	2.3	7	9
Chennai	1565	17.6	1	2
Pipavav	695	2.4	2	7
Tuticorin	620	73.5	0	0
Kolkata	577	24.0	0	0
Cochin	429	36.1	1	2
Hazira	303	0	1	1
Visakhapatnam	293	20.7	0	1
Krishnapatnam	119	44.5	0	1

Source: Drewry (2016) [9], Maritime Intelligence (2017) [26], and SLPA (2016) [27].

The following three assumptions are required to apply the proposed model to the study area. Firstly, transhipment was implemented only at the Colombo port. In other words, Indian ports with relatively higher numbers of services, such as Nhava Sheva or Mundra, are not considered transhipment ports. The previous assumption is based on the high cost of the cabotage policy in Indian feeder transport. Secondly, container cargo to/from European ports such as Hamburg and East Asian ports such as Busan are aggregated in Rotterdam and Shanghai, respectively. The third assumption is required to simplify calculations. Finally, the number of calls for South Asian ports (that is, Colombo and Indian ports) in one service is limited to less than three (that is

1 or 2), which is determined based on actual vessel deployment. As shown in Table 2, we developed a set of 265 services for the target origin and destination based on the first to third assumptions above. In addition to including cargo flow between India and other ports, these services also include cargo flow between East Asia and Europe. We grouped these services in a set of liner services (R), which deploys the optimum vessel type and service to transport all container cargoes between origin and destination ports by maximizing their profit.

Table 2. Research target services.

Liner Services	Port of Call
Europe-East Asia service	RTM/SHA/RTM
Europe-South Asiaast Asia service	RTM/IS(1)/SHA/RTM
	RTM/IS(1)/SHA/IS(2)/RTM
	RTM/SHA/IS(1)/RTM
	RTM/IS(1)/SHA/IS(2)/RTM
Europe-South Asia service	RTM/IS(1)/RTM
	RTM/IS(1)/IS(2)/RTM
East Asia-South Asia service	SHA/IS(1)/SHA
	SHA/IS(1)/IS(2)/SHA
RTM: Rotterdam, SHA: Shanghai, IS(n): *n*th port of call in Indian Subcontinent ports	

4.2. Input Values and Scenarios

Several input values were required to conduct the case study. The coefficient of cargo demand (θ) in Constraint 11 was utilized to increase cargo demand, similar to the scenario analysis. Note that cargo demand of each port at base case is listed in Table 1. The value of coefficient θ was prepared for nine cases (1.00, 1.39, 1.78, 2.17, 2.56, 2.95, 3.34, 3.73, and 4.11). According to IHS Global Insight, in 2030, the export/import container cargo demand in India will be 2.56 times higher than the current volume. Thus, we set $\theta = 2.56$. In addition, other values of θ were prepared with equal intervals to observe the effect of cargo demand on the transhipment ratio at Colombo Port. In this study, the shipping line can deploy a vessel (a) to each service from vessel type (A) in Table 3. Each vessel has a distinct gross tonnage, bunker price, and vessel cost. We defined the navigation speed (v^a) as 25 knots for all vessel types. Bunker price per ton is obtained from Ship & Bunker (BP = 661.75 USD/ton). Banker cost is dependent on the navigation speed and vessel size. Navigation speed is changeable in one sailing; however, consideration of such fluctuations makes the optimization process difficult. Thus, we use average speed, which is obtained from the MDS database. Similarly, bunker cost is different from each vessel size; however, as several studies assumed, the design speed is uniformly set if vessel size exceeds a certain size. For example, Akakura and Matsuda (2014) [28] concluded that navigation speed can be uniformly set as 24.6 knots for a 6357 TEU sized vessel and above. Therefore, we use 25 knots as an average navigation speed for all sized vessels. Besides, vessel speed has been reduced from the year 2015. Since vessel speed would be one of the variables to determine vessel deployment, consideration of change in vessel speed is important. This is a future work of this study. Note that the shipping line cannot deploy any vessels in any service owing to physical constraints on the vessels, such as the water depth of the ports.

Table 3. Vessel types (A).

Vessel Size [TEU] (s^a)	Tonnage [ton] (g^a)	Bunker Cost [USD/Hour] (bc^a)	Vessel Cost [USD] (vc^a)
6000	73,518	167	193,931
7500	87,794	209	214,595
9000	102,069	252	235,259
10,500	116,345	294	255,923
12,000	130,620	337	276,587
13,500	144,896	379	297,251
15,000	159,171	422	317,915
16,500	173,447	465	338,579
18,000	187,722	508	359,243
19,500	201,998	551	379,907
21,000	216,273	594	400,571
Source	database of MDS and Marine traffic	Notteboom and Cariou (2009) [29].	ITF (2015) [30]

As shown in Table 4, we consider three scenarios for the maximum vessel size in each port. Scenario 1 indicates the actual maximum vessel size calling at each port determined by the MDS database and Drewry [27]. Scenario 2 is the case where the maximum vessel size is increased by 3000 TEU more than those of Scenario 1 in all ports except the Colombo and Mundra. Moreover, scenario 2 assumes the development of future Indian local ports. For Scenario 3, the maximum vessel size increases for the Mundra and Colombo ports, where the constraints are not relaxed in Scenario 2. Consequently, we assume that in the future, 21,000 TEU-sized vessels can only be accommodated in the Mundra and Colombo ports. It is fair to consider that other ports can also be expanded to accommodate large-sized vessels due to the availability of sufficient hinterland. For example, Visakhapatnam and Krishnapatnam ports have sufficient hinterland for further expansion [31]. However, the demand for these ports is not as high as that of other popular Indian ports, such as Nhava Sheva and Mundra. Accordingly, we prepared scenarios for the maximum vessel size of each Indian and Colombo port. The data of other input values were sourced from SeaRoute.com, including freight rate, FLC, and navigation distance between ports.

Table 4. Scenarios for maximum vessel size for each port.

Port	Maximum Vessel Size [TEU]		
	Scenario 1 (Actual)	Scenario 2	Scenario 3
Nhava Sheva	12,000	**15,000**	15,000
Mundra	18,000	18,000	**21,000**
Chennai	6000	**9000**	9000
Pipavav	6000	**9000**	9000
Tuticorin	3000	**6000**	6000
Kolkata	2000	**5000**	5000
Cochin	6000	**9000**	9000
Hazira	9000	**12,000**	12,000
Visakhapatnam	6000	**9000**	9000
Krishnapatnam	6000	**9000**	9000
Colombo	18,000	18,000	**21,000**

5. Results and Discussion

5.1. Shipping Network

Table 5 shows the results of vessel deployments in Colombo and Indian ports connecting Europe and East Asia. As mentioned before, Europe and East Asia ports are aggregated into Rotterdam and Shanghai ports for simplicity. Note that we consider the total container volumes between the Indian subcontinent and Europe/East Asia, even though ports are aggregated. First, we discuss the impact of the changes in cargo demand, which is expressed by θ. As shown in Table 5, as the cargo demand increased, the number of deployed vessels in Indian ports also increased. Specifically, the number of deployed vessels increased from 4 (θ = 1.0) to 10 or 11 (θ = 2.56). The changing ratio is almost the same as the ratio of changes in cargo demand, such as from 1.0 to 2.56. Meanwhile, there were no drastic changes in the number of vessels deployed in the Colombo port with increasing cargo demand. Vessels deployed to Colombo port increased from three (θ = 1) to four (θ = 2.56) in scenario 1, which does not assume any developments in Indian ports. However, when the maximum vessel size of Indian ports increases, more vessels will be deployed in Indian ports. These results show that the number of direct services to Indian ports is expected to increase when the cargo demand of Indian ports increases. Importantly, the size of deployed vessels decreased in scenarios 2 and 3, which are Indian port development scenarios. In other words, the de-hubbing phenomenon (that is, calling trunk lines for Indian ports and skipping Colombo port) decreases vessel size because the demand originating at Indian ports is mostly satisfied by newly deployed trunk lines to Indian ports. It has significant impacts, particularly for Colombo port because this port has a high dependency on transhipment cargoes and vessels.

Table 5. Results of size of deployed vessels for Colombo and Indian ports.

			Number of Vessels	Deployed Vessel Size [TEU]
Coefficient of cargo demand $\theta = 1.0$.	Colombo	Scenario 1	3	15,000, 10,500, 6000
		Scenario 2	3	18,000, 10,500, 9000
		Scenario 3	3	21,000, 10,500, 6000
	Indian ports	Scenario 1	4	10,500, 6000 (3)
		Scenario 2	4	10,500, 9000, 6000 (2)
		Scenario 3	4	10,500, 6000 (3)
Coefficient of cargo demand $\theta = 2.56$.	Colombo	Scenario 1	4	18,000, 12,000, 10,500, 6000
		Scenario 2	3	9000, 6000 (2)
		Scenario 3	3	9000, 6000 (2)
	Indian ports	Scenario 1	10	12,000 (3), 10,500, 6000 (6)
		Scenario 2	11	13,500 (2), 12,000 (2), 10,500, 9000 (3), 7500, 6000 (2)
		Scenario 3	11	13,500 (2), 12,000 (2), 10,500, 9000 (3), 7500, 6000 (2)

Note (2)/(3): two/three vessels are deployed.

As shown in Table 4, scenario 2 assumes increases in the capacities of Indian ports, whereas scenario 1 reflects the actual status. If the cargo demand does not change in the future ($\theta = 1.0$), shipping lines deploy 9000 TEU-sized vessels in both Colombo and Indian ports in scenario 2, whereas 6000 TEU-sized vessels are deployed in scenario 1. As shown in Table 6, the result implies that the developments of Indian ports also contribute to the de-hubbing of the maritime network in this region under the condition of constant cargo demand ($\theta = 1.0$). Moreover, because larger vessels for Indian ports are deployed as direct calls, there could be significant impacts on the hub status of the Colombo port. The comparison between Scenarios 1 and 2 at θ = 2.56 shows that not only does the number of services calling at Colombo port decrease, but the vessel size also decreases because vessels with more than 10,000 TEUs no longer call at Colombo port. Meanwhile, the number of services calling at Indian ports increases from 10 (Scenario 1) to 11 (Scenario 2), and the vessel size also increases, with 13,500 TEU vessels calling at large Indian ports such as Nava Sheva and Mundra without calling for Colombo port in scenario 2. As shown in Table 1, the Nhava Sheva and Mundra ports have a large container volume in their hinterland; thus, these ports receive direct shipments to Europe and East Asia with large container vessels. In addition, relatively minor Indian ports such as Tuticorin, Krishnapatnam, and Visakhapatnam obtained direct routes to Europe and East Asia when large cargo demand cases and port developments were carried out. In addition, as shown in Table 7, the 13,500 TEU vessel does not call for Colombo port but direct to Europe and East Asia, which indicates that the de-hubbing phenomenon would progress if case cargo demand increases and Indian ports are developed. When comparing the number of vessels deployed at ports in the scenarios, Indian ports indicate a significant increase in the number of vessels when the cargo volume increases, even in the same scenario (scenario 2). For instance, they have only four vessels at a lower cargo demand ($\theta = 1$), which increases to 11 vessels at high cargo demand ($\theta = 2.56$). In contrast, the Colombo port experiences a reduction in vessel sizes, particularly in scenario 2, which has a high cargo demand at Indian ports. It implies that increased cargo demand at Indian ports could be mostly handled by the new mainline vessels calling at Indian ports, which inevitably decreases the overall network concentration at the Colombo port.

Table 6. Results of optimized services at θ = 1.0.

Coefficient of Cargo Demand $\theta = 1.0$			
Vessel Size (TEU)	**Port of Call**		
	Scenario 1	**Scenario 2**	**Scenario 3**
21,000	-	-	RTM/CMB/SHA/RTM
18,000	RTM/SHA/RTM	RTM/SHA/RTM	-
18,000	-	RTM/CMB/SHA/RTM	-
15,000	RTM/CMB/SHA/RTM	-	-
10,500	SHA/NSA/CMB/SHA	SHA/NSA/CMB/SHA	SHA/NSA/CMB/SHA
9000	-	RTM/SHA/MAA/CMB/RTM	-
6000	RTM/KOC/MAA/SHA/RTM	RTM/MUN/NSA/RTM	RTM/MUN/NSA/RTM
6000	SHA/MUN/PAV/SHA	SHA/MUN/PAV/SHA	SHA/MUN/PAV/SHA
6000	RTM/SHA/MAA/CMB/RTM	-	RTM/SHA/MAA/CMB/RTM
6000	RTM/MUN/NSA/RTM	-	-

Table 7. Results of optimized services at θ = 2.56.

Coefficient of Cargo Demand $\theta = 2.56$			
Vessel Size (TEU)	**Port of Calls**		
	Scenario 1	**Scenario 2**	**Scenario 3**
18,000	RTM/SHA/RTM	RTM/SHA/RTM	RTM/SHA/RTM
18,000	RTM/SHA/CMB/RTM	-	-
13,500	-	RTM/MUN/NSA/SHA/RTM	RTM/MUN/NSA/SHA/RTM
13,500			SHA/NSA/SHA
12,000	RTM/NSA/CMB/SHA/RTM	RTM/MUN/NSA/SHA/RTM	RTM/MUN/NSA/SHA/RTM
12,000	SHA/MUN/SHA	SHA/NSA/SHA	SHA/NSA/SHA
12,000	RTM/SHA/NSA/RTM	-	-
10,500	SHA/NSA/CMB/SHA	SHA/MUN/HZR/SHA	SHA/MUN/HZR/SHA
9000	-	RTM/CMB/MAA/SHA/RTM	RTM/CMB/MAA/SHA/RTM
9000	-	RTM/SHA/PAV/MUN/RTM	RTM/SHA/PAV/MUN/RTM
9000	-	RTM/SHA/KOC/NSA/RTM	RTM/SHA/KOC/NSA/RTM
7500	-	SHA/MAA/KRI/SHA	SHA/MAA/KRI/SHA
6000	SHA/CMB/MAA/SHA	SHA/CMB/VTZ/SHA	SHA/CMB/VTZ/SHA
6000	SHA/PAV/NSA/SHA	SHA/TUT/CMB/SHA	SHA/TUT/CMB/SHA
6000	SHA/MAA/VTZ/SHA	-	-
6000	RTM/MUN/MAA/RTM	-	-
6000	RTM/SHA/KOC/MUN/RTM	-	-
6000	RTM/SHA/HZR/PAV/RTM	-	-

Scenario 3 assumes a capacity increase at Mundra and Colombo ports to accommodate up to 21,000 TEU vessels. In Scenario 3, a 6000 TEU vessel is deployed instead of the 9000 TEU vessel deployed in Scenario 2; simultaneously, a 21,000 TEU vessel is deployed in Colombo port in scenario 3. This shows that deploying ultra-large-sized vessels (that is 21,000 TEU) in Colombo port is cost-effective for shipping lines, enabling them to achieve economies of scale. Thus, it is crucial to develop Colombo port to call ultra-large vessels. In the cargo demand increasing case ($\theta = 2.56$), as shown in scenarios 2 and 3 in Table 7, the number and size of deployed vessels in Colombo port decrease with the development of Indian ports. As mentioned before, shipping lines enable the deployment of vessels of various sizes, including direct services to Europe and East Asia from Indian ports, because Indian ports are developed (scenarios 2 and 3). From these results, the development of Indian ports effectively proceeds to the de-hubbing of the maritime network, particularly in the case of increased cargo demand. It also implies that deploying ultra-large vessels (that is 21,000 TEU) at the Colombo port is insufficient to exceed cost-effectiveness than direct shipment in the case of high cargo demand in the future.

Tables 6 and 7 indicate the detailed ports of call related to the services in each scenario when θ = 1.0 and θ = 2.56, respectively. Accordingly, a significant increase in the number of services can be observed for high cargo demand in all three scenarios. Moreover, the number of common services calling at both Colombo and Indian ports has increased with increasing cargo demand, thus reducing the hub role of Colombo because the mainline services mostly called only Colombo before the increase in the cargo demand.

Figure 2 summarizes the annualized slot capacities (ASC) of ports in each scenario to provide a better understanding of the effects of vessel deployment at individual ports in the Indian subcontinent. The ASCs were calculated based on the services and vessel deployments mentioned in Tables 6 and 7, which result from the MILP model. Accordingly, a significant difference could be observed in the ASCs of individual ports when changing cargo demand. The ASC of Colombo indicates a significant drop, while that of the Nhava Sheva indicates significant growth in scenarios 2 and 3. Apart from the Nhava Sheva port, Mundra indicates the second-largest ASC after increasing cargo demand. Moreover, when compared to the actual situation given in Scenario 1, the number of Indian ports directly called mainline vessels increased in scenarios 2 and 3. For instance, ports such as Krishnapatnam, Tuticorin, Vishakhapatnam, and Hazira are not being called mainline vessels in scenario 1 with low cargo demand, although those ports are called by scenarios 2 and 3, particularly with high cargo demand. Apart from the effects on ASC due to port developments in scenarios 2 and 3, a significant increase in ASC can be observed when comparing low and high cargo demands, even in scenario 1 without any port development. When considering Scenario 1, Colombo port still receives the highest ASC from these services, even with the high cargo demand of India. Thus, insufficient port infrastructure in India plays a predominant role in maintaining the hub status of Colombo. Overall, in scenarios 2 and 3, 10 Indian sub-continent ports are referred to as mainline services with high cargo demand when compared to the four ports with low cargo demand, which directly indicates the de-hubbing phenomenon. However, the ASC analysis only indicates the slot capacities of services and does not indicate the actual allocation of slots on individual ports by shipping lines.

5.2. Transhipment Cargo at Port of Colombo

Figure 3a,b show the total cargo volume of transhipment cargo via Colombo and the ratio of transhipment cargo in Colombo port, respectively. As shown in Figure 3a, the amount of transhipment in Scenario 1 increases as cargo demand increases, and those in Scenarios 2 and 3 fluctuate with an increase in cargo demand. This implies that the Colombo port would deal with a larger volume of cargo as cargo demand originating in India increases without the development of Indian ports (scenario 1). However, if Indian ports carry out port developments and enlarge the maximum vessel size accommodated, it would be difficult for the Colombo port to increase the volume of cargo even if Colombo port implements port expansion in scenario 3.

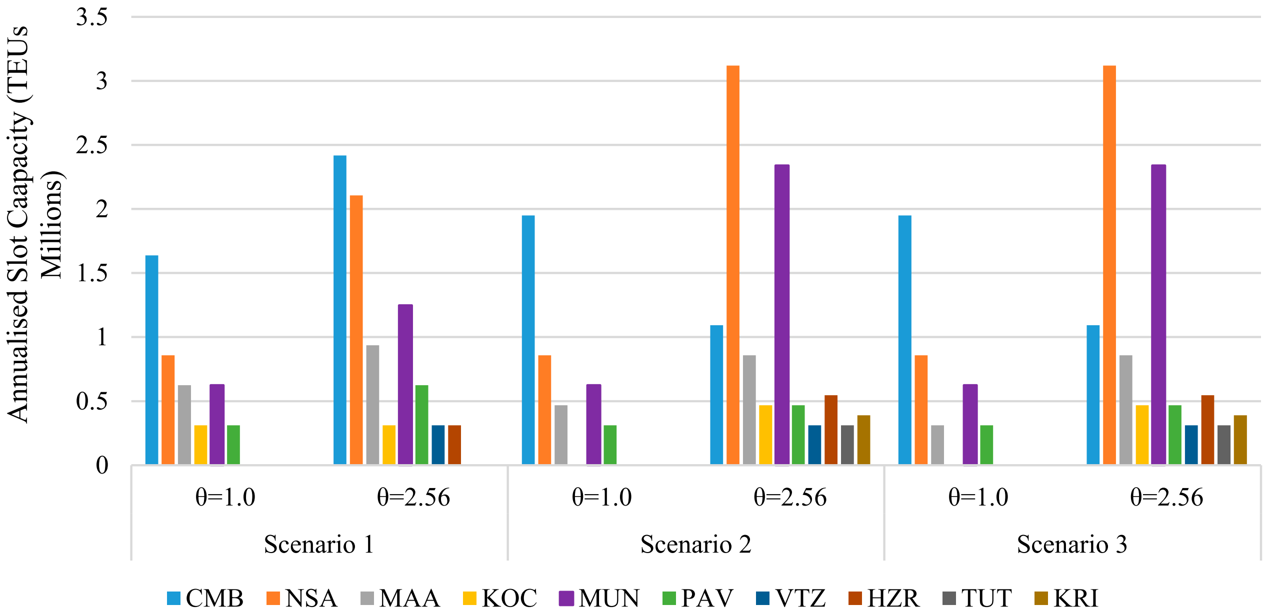

Figure 2. Annualized Slot Capacity of Services Calling at Indian Subcontinent ports.

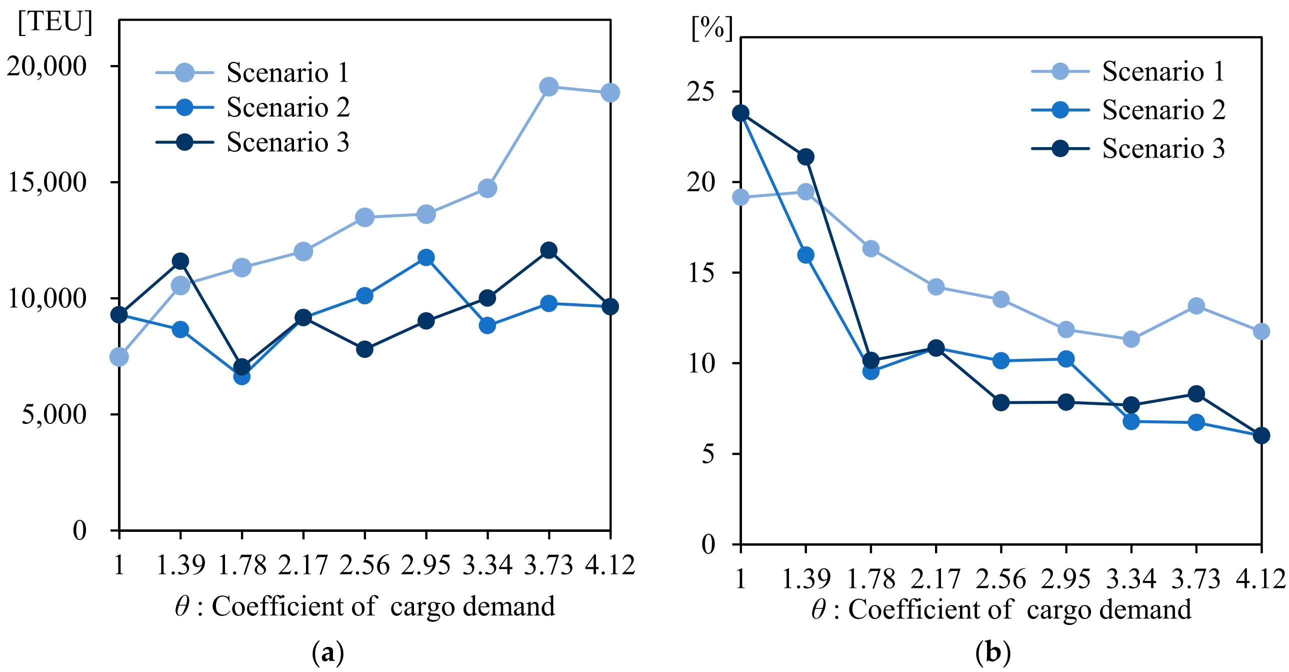

Figure 3. Result of transhipment cargo in each demand. (**a**) Total amount of transhipment via Colombo. (**b**) Ratio of transhipment cargo in Colombo.

Furthermore, as shown in Figure 3b, the transhipment ratios of Colombo port decrease as cargo demand increases in all scenarios. Note that the transhipment ratio in Figure 3b defines the transhipment volume at the Colombo port divided by the total container volume originating at Indian ports. In particular, the transhipment ratio of Scenarios 2 and 3 sharply decreases when the coefficient of cargo demand exceeds 1.78, although the container volume handled in Colombo port neither increases nor decreases, as shown in Figure 3a. However, in Scenario 1, the transhipment volume handled at Colombo indicates a significant increase in cargo demand despite the reduction in transhipment ratio. These results show that the de-hubbing phenomenon proceeds as cargo demand increases. However, the cargo volume at Colombo port remains almost constant despite certain fluctuations, which can be attributed to the increase in the total container demand in this region, particularly in Indian containers. Note that the development of the Hambantota port in Sri Lanka has not been considered in this study because no specific route services of container vessels were identified in our database. However, the Hambantota port may improve Sri Lanka's competitiveness with respect to international hubs because this port is located in the proximity of the main sea route compared to the Colombo port. In this case, the deviation cost for shipping lines is expected to be small and particularly advantageous for the east coast of India. The consideration of the Hambantota port is a critical aspect for future research.

5.3. Sensitivity Analysis

Several input values were set in the simulation results addressed above, and certain input values influence the simulation results. In particular, the feeder link cost (FLC), which indicates the feeder-related cost between Indian ports and Colombo port, and operation and fixed cost (OFC), which indicates the vessel operation costs, would significantly affect vessel deployments and even transhipment volume at Colombo port. However, owing to the lack of actual data, these values were estimated by the authors based on real data such as navigation distance and velocity. Thus, we conducted a sensitivity analysis by assuming a 10% discount and rise for both FLC and OFC in scenario 1 with all container demand cases (θ = 1.0–4.12).

Figure 4 shows the results of the sensitivity analysis as the ratio of transhipment cargo at Colombo port. As shown in Figure 4, drastic changes were not observed by changing the FLC and OFC. However, some fluctuations in the results were observed when the coefficients of cargo demand are 2.56 and 2.95. For θ values of 2.56 and 2.95, because the FLC is 10% lower than the base case, the transhipment ratio at the Colombo port increases by approximately 2 points and 4 points from the base case, respectively. The result was expected and reasonable because the comparative feeder cost of direct shipment is reduced. Specifically, 6000 TEU vessels newly call for Colombo port connecting with East Asian ports by reducing FLC by 10%. In the case of a 10% reduction in OFC, the transhipment ratio at the Colombo port is decreased. Moreover, it is reasonable because direct shipments increased compared to transhipment routes when OFC decreases. In addition, with a lower OFC, shipping lines would not consider a comparatively longer deviation distance of Indian ports as a significant disadvantage because it represents only a minor portion of the total voyage cost; however, they consider the advantages of calling directly in India, which is the ultimate origin/destination of the cargo. This scenario is especially important for shipping lines when India has high cargo demand in the future. From these results of the sensitivity analysis, changes in the FLC and OFC in the transhipment ratio are appropriately obtained, which implies that the model structure may be appropriate.

In addition, as mentioned before, if θ is lower than 2.56 and greater than 2.95, drastic changes in the transhipment ratio at Colombo are not observed by changing FLC and OFC. When θ is lower than 2.56, it may not be economical for shipping lines to increase direct services at Indian ports considering only the changes in FLC and OFC, possibly due to insufficient cargo demand. Therefore, the variation in the transhipment ratio is almost identical to that shown in Figure 3b, which is observed without any changes in the FLC and OFC. Similarly, when θ is greater than 2.95, changes in FLC and OFC are not sufficient to attract more direct services at Indian ports than the level observed in Figure 3b. Moreover, because we conduct sensitivity analysis only with scenario 1 without any development of Indian ports, it is reasonable to not have significant changes in transhipment ratio at Colombo because shipping lines would not have more economic alternatives than using Colombo as a transhipment hub because of insufficient infrastructure at Indian ports.

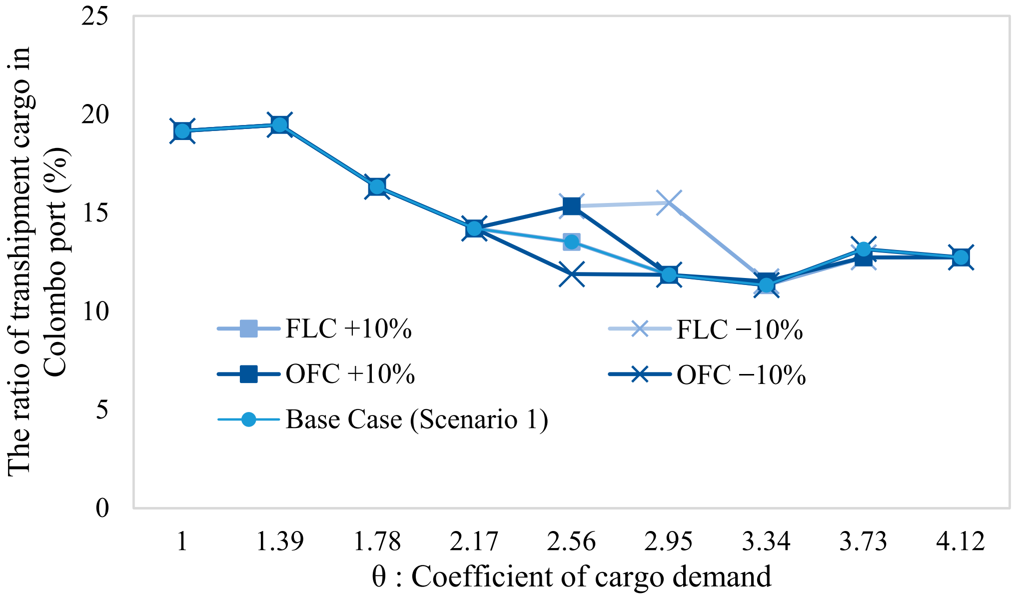

Figure 4. The ratio of transhipment cargo in Colombo port by changing FLC and OFC.

6. Conclusions

This study aims to clarify how port developments and container cargo demand of source countries impact maritime network selection such as de-hubbing from the perspective of shipping lines. The case study considers India as the source country of container cargoes and the Colombo port as a regional hub port. We develop a mixed integer linear programming model to describe the transhipment via the Colombo port and direct shipment in Indian ports. From the scenario analysis of the developed model, the following implications were obtained.

Firstly, the number of deployed vessels, particularly direct shipment services to Europe and East Asia in Indian ports, increased as cargo demand increased. Meanwhile, the number of vessels deployed in Colombo decreased slightly. Vessels deployed to Colombo port increased with increasing container demand in the region in the case of Scenario 1, which reflects the current port status. These results indicate that the number of direct services to Indian ports is expected to increase when the cargo demand of Indian ports increases, and the port development of Indian ports is conducted. The de-hubbing phenomenon decreases vessel size, calling for Colombo port because the demand originating at Indian ports is mostly satisfied by newly deployed trunk lines to Indian ports. Nhava Sheva and Mundra ports exhibit a large container volume in their hinterland; thus, these ports received direct shipments to Europe and East Asia with large container vessels when the container demand increased in this region. Meanwhile, relatively minor Indian ports, such as Tuticorin, Krishnapatnam, and Visakhapatnam, obtain direct routes to Europe and East Asia in case of large cargo demand and when port developments are conducted. Overall, Indian ports have the potential to call larger-sized vessels if cargo demand will increase in the future. However, the ultra-large-sized vessel will not be deployed for Indian ports when the Colombo port is capable of accepting 21,000 TEU vessels primarily because the deployment of an ultra-large-sized vessel to the Colombo port is more cost-effective. When considering transhipment handling, although the transhipment volume handled in Colombo port does not indicate a significant change even with Indian port developments, the transhipment ratio (%) of Colombo port declines considerably due to the growth of Indian cargo demand combined with their port developments.

This study derives significant policy implications on the port development aspects of Indian subcontinent ports by considering the growth of their cargo demand. Currently, several port development projects are being carried out in both Sri Lanka and India, focusing on the target ports included in this study. Therefore, if Colombo port expects to maintain its hub status, it is critical to consider various other incentives to attract and retain mainline carriers in addition to expanding its port infrastructure. Currently, Colombo port deploys several strategies to attract and retain shipping lines, especially by offering favourable berthing windows and dedicated berths and terminals to major shipping lines and involving private sector and global terminal operators with strong networks and market power in the operation of Colombo port by offering concession terminals, etc. Similarly, if India expects to receive direct calls from mainlines, it is important not only to develop their port infrastructure but also to increase their cargo demand. However, the scale of port infrastructure development must still be considered to avoid overdevelopment and underutilized port facilities, because shipping lines are not interested in deploying ultra-large-sized vessels in Indian ports, possibly because of the advantages of the hub-and-spoke network structure centred in Colombo port with high capital and operating costs of those large container vessels.

This study has several limitations. First, we do not consider competition between shipping lines. Because Colombo port is located at the trunk line between Europe and Asia, competition between shipping lines might affect the results. Moreover, although we assumed that the main shipping line does not have to pay charges to the feeder shipping line for simplicity of calculation, feeder link cost would be a significant factor for the de-hubbing phenomenon in the practical scenario. Another limitation is that this study only considers the liner services to Europe or Asia. It is preferable to consider other services to obtain more accurate results, such as North American routes. These issues must be investigated in future studies. Moreover, the development of the Hambantota port of Sri Lanka has not been considered in this study because no specific route services of container vessels were identified in our database. However, considering that the Hambantota port may improve Sri Lanka's competitiveness with respect to international hubs because this port is located in the proximity of the main sea route relative to the Colombo port, the deviation cost for shipping lines is expected to be small and particularly advantageous for the east coast of India. Therefore, the consideration of the Hambantota port is an important aspect for future studies.

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Nomenclature

r	Liner service
a	Vessel type
p	Port in research area
o	Origin port
d	Destination port
h	Hub port
R	Set of liner services
A	Set of vessel types
P	Set of ports in research area
W	Set of origin and destination port pairs
$\widetilde{X}_{od}$	Cargo volume transported directly from port o to port d (TEU/week)

$\widetilde{x}_{od}^{r}$	Cargo volume directly transported from port o to port d in service r (TEU/week)
$\hat{X}_{od}$	Cargo volume transported from port o to port d by transhipment (TEU/week)
$\hat{x}_{od}^{r}$	Cargo volume transported from port o to port d by transhipment in service r (TEU/week)
y_r^a	A binary variable which takes 1 if service r is served by vessel type a and otherwise 0
z_r^p	A binary variable which takes 1 if service r includes port p and otherwise 0
$w_{r,i}^{o,od}$	A binary variable which takes 1 if port o is i-th port in service r
Ps	Profit of shipping line in a week (USD)
$\widetilde{F}_{od}$	Freight rate directly transported from port o to port d (USD/TEU)
$\hat{F}_{od}$	Freight rate from port o to port d in transhipment (USD/TEU)
bc^a	Bunker cost of vessel type a (USD/hour)
lc_p	Loading or unloading cost at port p (USD/TEU)
fc_{od}	Feeder link cost (FLC) from port o to port d (USD/TEU)
vc^a	Vessel cost of vessel type a which indicates operation and fixed cost (OFC) (USD)
pc_p	Port charge at port p (USD)
s^a	Vessel size of vessel type a (TEU)
v^a	Navigation speed of vessel type a (TEU)
$D_{r,i}$	Navigation distance from $i-1$ th port to i-th port in service r (hour)
N_r	Number of vessels in service r
T_p	Average vessel turnaround time at port p (hour)
Q_{od}	Container cargo demand from port o to port d (TEU/week)
$q_{r,i}$	Cargo volume on from $i-1$ th port to i-th in service r (TEU)
M	A large positive constant
θ	Coefficient for scenario analysis on future cargo demand

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Chinese Cruisers' Preference, Travel Constraints, and Behavioural Intention: Experience from the Arctic Cruise Market

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Abstract: Global climate change accelerates ice melting in the Arctic region, making Arctic shipping possible and revealing a new door to develop cruise tourism. The rapid expansion of cruise tourism into the Arctic region has posed substantial implications for the cruise industry, including opportunities and challenges. This study investigates the Chinese cruise industry and the encounters and obstacles that have unfolded in the Arctic cruise market. The study also explores the Chinese cruisers' travel constraints, preferences, and behavioral intention to the Arctic region. The implications of the findings are drawn to develop the entire Arctic cruise market. This study also provides invaluable insight into the cruise industry's adaptation strategies and practices and relevant supporting business sectors.

Keywords: Chinese cruisers; arctic region; travel constraint; preference; behavioral intention

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1. Introduction

Global warming has generated significant transformation in the cruise industry in the last few decades. The sea melting of sea ice in the Arctic Ocean has created a new cruise market and the future of navigation. To this end, it is expected that cruise shipping activity in the Arctic will rise remarkably, notably in exploration activities and cruise tourism [1,2]. Over the last three winters, temperatures in the central Arctic were six degrees celsius above average, and 278 gigatonnes of ice were lost from the Greenland Ice Sheet per year [3]. In this sense, a meteorological forecast is that the decrease of Arctic Sea ice will speed up. Numerous researchers and mass media present the expectation of Arctic tourism in various phases, such as an abundance of cruises in the next few years, now entering a maturing phase, cruise industry's inevitable growth in the Arctic, and the fast-growing market [4,5].

Nevertheless, the Arctic region is in a growth stage due to the fresh introduction of innovative cruise tourism products consisting of unexpected cultures, exciting shore excursions, exotic experiences, and attractive cruising destinations [6]. Since 2009, cruise tourism has fully covered all Arctic destinations [1]. Specifically, the critical issue in investigating Arctic tourism is in locating its boundaries. The Arctic region covers Alaska, Canada, Finland, Greenland (Denmark), Iceland, Norway, Russia, and Sweden. This region is difficult to access and remote with the lack of the ability to move across the entire Circumpolar North, is subject to human capital issues (i.e., inadequate know-how), and occurs in vulnerable natural and weak culture conditions [6].

Cruise travel to the Arctic region has arisen since 1984. The effect of global climate change enhances cruise ships' abilities to more easily access remote Canadian Arctic communities [4,7]. The notable change in the Arctic region is due to the rise in temperatures.

The cruise industry now strives towards Antarctica and Arctic regions by expanding between the poles, providing more than 200 destinations in 30 countries. As a result, Arctic cruise passengers will remarkably grow from 242,154 in 2018 to 412,153 in 2027. At the same time, the number of berths in the Arctic region will increase from 9637 in 2018 to 14,415 in 2027. To accommodate these, the number of Arctic cruise ships will increase from 73 ships in 2018 to 94 ships in 2027 [8].

Previous studies on Arctic cruise shipping have focused on tourism management rather than the maritime transport management discipline [4,9–11]. Only Fedi et al. [12] studied the transportation of Arctic cruising, highlighting cruise ship casualty and passenger safety. In addition, considerable works focus on economics, cruise shipping management, and day-to-day cruise shipping operational activities. Some studies have concentrated on the customer perceptions of the cruise industry, safety management, behavioral aspects of inter-firm relations, cruise ship operational efficiency, cruise shipping regulations and governance, and the portfolio analysis of the cruise shipping sector [13–15]. However, most studies focus on the cruise shipping market in the European, North American, and Asian regions. An emerging cruise market in the Arctic region is still an under-researched topic and seriously overlooked. Lasserre and Pelletier [16] (p. 1465) argued that stakeholders' attitudes towards cruising in the Arctic region are blurred and confident and that "scenarios for the development of marine traffic in the Arctic remain highly speculative". Therefore, it is expected that Chinese cruisers will be the largest cruise market in the Arctic region in 2022 [17]. In addition, the improvement of COVID-19 treatments, the introduction of a vaccination program, the commencement of vaccine passports for cruise travel, and the emergence of compensatory consumption motivate Chinese cruisers to take expedition cruises to the Arctic again. In general, Panahi et al. [5] indicated that Arctic research is scarce in academic research studies, although there is an upward trend towards international shipping activities in the Arctic region. Cai et al. [18] addressed previous studies investigating tourists' customer value, weather perceptions, food tourism, and niche market segmentation (e.g., adventure tourism, wellness tourism) in the Arctic region. Obviously, some critical issues of Arctic cruise shipping related to Chinese cruiser's travel constraints, preferences, and behavioral intention to the Arctic region are neglected. The Chinese cruise industry's response to a challenge in the Arctic cruise market is overlooked. These will be addressed in the present study.

This study investigates the Chinese cruise industry's encounters that have unfolded obstacles in the Arctic cruise market. The study also explores the Chinese cruisers' travel constraints, preferences, and behavioral intention to the Arctic region. This study gives fundamental work and invaluable insight into the cruise industry's adaptation strategies and practices, and other supporting business sectors.

The paper is divided into four main sections. Section 1 provides the research background, settings, and objectives. Section 2 discusses the key concept of cruiser's travel constraints, preferences, and behavioral intention. Section 3 explains the research methodology, while Section 4 presents investigating the China cruise market in the Polar region from products and tourists' perspectives. The conclusion is provided in Section 5.

2. Literature Reviews

Cruise tourism is a significant contributor to the local economy in different countries across various parts of the world [19,20]. Cruise tourism has experienced steady growth with an average growth rate of 8.1% per year in the number of cruisers onboard since the 1980s [21]. Due to the Arctic region including a number of new destinations, it stimulates the Chinese cruisers to visit again by enchanting destination experiences. Destination tourism creates supporting industries and increases regional economic development in the future [22]. Importantly, the unique destination image is a critical element that affects tourists' destination preferences, satisfaction, behavioral intentions, and decision-making processes. It is practicable that the tourists' perception of a specific destination involves exceptional measurement context and content instead of depending only on pre-determined measures drawn from various contexts [19]. To a large extent, it is useful for cruise lines to design, plan, and implement various marketing strategies into diverse market segments such as families, old-retired people, and young consumers.

Various studies have explored the associations between the destination image and tourists' preference and visit intention [23]. Moreover, many studies have focused on the influence of prior travel experience on destination image [24], the evolution of destination image [25], and the dimensions of destination image [26]. Lee et al. [27] further elaborated intentional creation in advance due to the strength of the preference for the product. Marti [28] noted that cruisers are concerned about staying time on a cruise and each port. Sun et al. [22] further explained that most cruisers intend to spend more time and money onshore rather than offshore. Indeed, Chinese cruisers recognized the importance of visiting tourist attractions onshore to create a memorable experience [29] and obtain knowledge of cultures and history [30]. In other words, whole day stays and overnight at port enhance the competitiveness of Arctic cruise tourism.

A positive country image may be considered as a distinguishing factor for current highly competitive destinations [31–33]. This would determine the tourists' decision-making process. Despite the fact that potential tourists have favorable image perceptions in the direction of a destination, they may not prefer to visit that place because of the negative perceptions of the country generally. In the Arctic region, a series of unpleasant messages consists of security, economic development, extreme weather conditions, and a vulnerable cultural problem. This is completely different in accordance with tourists' understanding of the destination. To this end, this creates misalignment between the destination image and country image, especially in a lack of relevant experience with the destination. Nevertheless, the concept of a country image is seriously lacking in tourism literature [19].

Choi and Cai [34] and Chaulagain et al. [19] identified that there was a close relationship among tourists' preferences, behavioral intentions, and the destination image. Gnoth [35] (p. 286) also reflected that the tourism research corresponds to the enlargement of the consumer behavior research area, including motivation and intention formation, the actual behavior and experience, and evaluation and consequences. Therefore, tourism not only considers economic and social circumstances but also concerns about psychological concepts [27]. However, a few studies have investigated the interaction between these constructs. Indeed, the country image affects the tourists' destination image perceptions and their behavioral intention to visit that country as a tourism destination [19]. To this end, it takes into account country image in the present study.

Hung and Petrick [21] elucidated that the notion of constraints has been widely adopted in leisure activities. Cruise Lines International Association (CLIA) [36] (p. 3) reinforced "the cruise industry is the most exciting growth category in the entire leisure market". However, the establishment of a measurement scale for constraints to cruise travel or adopting the concept of travel constraints examining the limitation of the cruisers' decision to take a cruise vacation is under-researched. Potential travel constraints foster clarifying as intentions do not continually foresee behavior [27]. These perceived behavioral controls impact both behaviors and intentions. The establishment of leisure constraints as a multi-dimensional construct has encouraged the robust assessment of constraints to be more organized [21]. The resulting measurement scale has demonstrated acceptable reliability and validity. Lee et al. [37] explored the relationships between three inter-related concepts: Travel constraints, learned helplessness, and intention to travel. They found that the three sub-dimensions of constraints impose no significant influence on travel intentions. However, two of the three dimensions (i.e., intrinsic and environmental) are statistically significantly associated with learned helplessness.

Hung and Petrick [38] applied the Motivation Opportunity Ability (MOA) model to explain travel intentions. The MOA model suggests that motivation, opportunity, and ability are major factors influencing travel intentions. Chen et al. [39] assessed the relationship between travel constraints and the destination image of Brunei from a young travelers' perspective. The study showed a positive relationship between travel constraints and destination during the early decision-making process. Lu et al. [40] provided the empirical examination of the seniors' travel behavior and time perspectives. Travel motivations fully mediate the associations between time perspectives and travel intention. Petrick [41] segmented that various cruise passengers based on their price sensitivity to determine if price-sensitive markets are desirable. The results revealed that less price-sensitive visitors are more likely to spend more, while more price-sensitive visitors are more likely to evaluate their experiences positively.

Ng et al. [42] examined the effect of cultural distance on tourists' destination choices. The perceived cultural distance measure appears to be a better predictor for cruiser intention. Wu et al. [43] proposed a multi-dimensional and hierarchical model and identified significant relationships among experiential quality, experiential value, experiential satisfaction, and behavioral intentions. Le and Arcodia [44] synthesized the existing knowledge on the role of risk perception in cruising, explored theories underpinning risk perception and its measurements, and identified key factors influencing risk perception.

Constraints are core elements that refrain people from continuing or launching to take a cruise. Recognizing the travel constraints helps to identify the inconsistency between actual and estimated cruise tourism performance and provides a useful reference for designing comprehensive marketing campaigns to investigate potential markets. The aforementioned Arctic cruise market is recognized as a fast-growing and promising cruise market in the forthcoming years [4]. In the study, a compelling research question relevant to this scenario is: Why do people not cruise even when they are interested in Arctic cruising? To respond to the research question, the three main kinds of leisure constraints (i.e., intrapersonal, interpersonal, and structural) are required to conduct a thorough analysis [45]. Intrapersonal constraints refer to the psychological conditions of an individual consisting of their attitude, interest, and personality towards Arctic cruises. Interpersonal constraints identify the interface between potential participants and others, for instance, their friends and family members. Structural constraints are classified as external factors, such as weak transportation systems and poor facilities that demotivate possible cruisers.

3. Methodology

In this study, we mainly adopt the case study approach to fill the research gap. Based on Di Vaio et al. [46], "the case study approach is a useful method for examining phenomena still unexplored. The case study allows the investigation of phenomena separately from the context examining specific variables." Every single case study has to be precisely exhibited. Specifically, the case study method is mainly applied as a qualitative method instead of a quantitative method. Therefore, we concentrate on a rigorous case investigation of historical data and archives. The quantitative data method is generally used to assess common phenomena or situations. Eventually, the conducted case study is expected to ensure a robust interpretation and exploration of the collected data and draw the key conclusions about the Chinese cruise industry encounters and the unfolded obstacles in the Arctic cruise market, as well as Chinese cruisers' travel constraints, preferences, and behavioral intention towards the Arctic region.

4. Chinese Cruise Market in Polar Region

With the transformation of tourism product position and the increasing tourism demand in recent years, various individualized tourism products have been developed to satisfy the current and potential tourists' demands and preferences. In addition, local residents' consumption level has been continuously upgraded, and with the rapid integration of culture and tourism industry, the outbound tourism system is extensively enlarged. Therefore, high-end outbound tourism has entered the most selective category of tourists. Under these circumstances, mysterious and challenging polar exploration tourism has widely raised concerns and has been praised.

In the context of global integration, tourists are allowed free access to various countries. This can speed up the development of tourist attractions and routes. Chinese tourists have gradually become an important part of the polar tourism market and are constantly expanding. Taking Antarctic tourism as an example, according to the International Association of Antarctic Tour Operators (IAATO) information, the number of Chinese tourists to Antarctica will exceed that of the United States in the Antarctic season from 2022 to 2023. China has become the largest source of tourists in Antarctic tourism [17]. Currently, a cruise is the main way to participate in polar tourism. As far as the existing cruise market situation is concerned, the cruise tourism products are getting more diversified, and the enlargement of polar routes inclines towards maturity. Accordingly, an increasing number of tourists participate in the wave of polar cruise tourism.

4.1. Cruise Products

4.1.1. Characteristics of Cruise Routes

Regarding analyzing the characteristics of cruise routes, this paper obtains 85 cruise routes of 14 cruise ships from 9 cruise companies released on two well-known domestic travel websites of *C-trip* (The Strategies of Cruise Trip and Cruise Itineraries https://cruise.ctrip.com/, accessed on 20 December 2021) and *Tongcheng* (Travel Go. http://www.ly.com/, accessed on 10 December 2021). Based on this data, the study combined the key characteristics of the Chinese polar cruise tourism market: Departure port, route length, and cruise lines. General speaking, the distribution of departure ports and ports of calls of polar cruises is relatively concentrated. This is not a regional concentration, but it is distributed in the focused area.

In the Arctic routes, departure ports are Longyearbyen (Norway), Murmansk (Russia), Reykjavik (Iceland), Warnemunde (Berlin), Hamburg (Germany), and Amsterdam (Netherlands). More than 70% of the cruise routes are from Longyearbyen. For the departure ports of the Antarctic routes, most cruise routes depart from Ushuaia (Argentina), with a high proportion of 81.82%. The details of departure ports are provided in Table 1.

Table 1. List of departure ports.

Area	Departure Port	Frequency	Shore of Total (%)
Arctic routes	Longyearbyen (Norway)	47	74.6
	Murmansk (Russia)	7	11.11
	Reykjavik (Iceland)	5	7.94
	Warnemunde (Berlin)	3	4.76
	Amsterdam (The Netherlands)	1	1.59
	Total	63	100
Antarctic routes	Ushuaia (Argentina)	18	81.82
	San Antonio (Chile)	1	4.55
	Buenos Aires (Argentina)	2	9.09
	Los Angeles (USA)	1	4.55
	Total	22	100

Tables 2 and 3 show the details and features of ports of call. Table 2 shows that the top three ports of call of the Arctic routes are Svalbard (Norway), Spitsbergen (Norway), and Ny-Alesund (Norway). The frequency contributes 24.89%, 11.76%, and 7.69% of total calls, respectively. The Antarctic routes (Table 3) show that Antarctic Peninsula and the South Shetland Islands are called by cruise ships the most, with the frequency of calling higher than 70%.

The trip duration is between 16 and 25 days. A 16-day journey accounts for the highest proportion, followed by a 17-day journey, which accounted for 11.8%. The rest are 18-day, 11-day, and 19-day journeys generating 10.6%, 8.2%, 7.1%, and 7.1% of the total frequency, as shown in Figure 1.

Table 2. List of ports of calls (landing place) in the Arctic.

No.	Port of Call (Destination)	Frequency	Share of Total (%)
1	Svalbard (Norway)	55	24.89
2	Spitsbergen (Norway)	26	11.76
3	Norway, Ny-Alesund (Norway)	17	7.69
4	Jan Mayen	14	6.33
5	Signehamna	10	4.52
6	Ísafjörður (Iceland)	8	3.62
7	Hornsund (Norway)	7	3.17
8	Franz Josef Land	7	3.17
9	Stykkishólmur	6	2.71
10	Scoresby Sound	6	2.71
11	Ilulissat (Greenland)	6	2.71
12	Reykjavik (Iceland)	6	2.71
13	Ittoqqortoormiit	4	1.81
14	Master Vig Port	4	1.81
15	Barentsburg	4	1.81
16	Disko (Greenland)	3	1.36
17	Kvalhovden (Norway)	3	1.36
18	Molde Port (Norway)	3	1.36
19	Longyearbyen (Norway)	3	1.36
20	Akureyri (Iceland)	3	1.36
21	Nuuk (Greenland)	3	1.36
22	Honningsvag port (Norway)	3	1.36
23	Qaqortoq (Greenland)	3	1.36
24	Malmo (Copenhagen)	3	1.36
25	Antarctica haven	3	1.36
26	Tromso (Norway)	2	0.90
27	Hellesylt (Norway)	2	0.90
28	Stavanger (Norway)	2	0.90
29	Cornwall (England)	2	0.90
30	Eidfjord Port	1	0.45
31	Bergen (Norway)	1	0.45
32	Kirkwall (England)	1	0.45
	Total	221	100

Table 3. List of ports of calls (landing place) in Antarctica.

No.	Port of Call (Destination)	Frequency	Share of Total (%)
1	Antarctic Peninsula	47	54.02
2	South Shetland Islands (Antarctica)	15	17.24
3	Montevideo (Uruguay)	4	4.60
4	Falkland Islands	4	4.60
5	Punta Arenas (Chile)	3	3.45
6	Puerto Montt (Chile)	2	2.30
7	Cape Horn (Chile)	2	2.30
8	Cabo San Lucas (Mexico)	1	1.15
9	San Antonio (Chile)	1	1.15
10	Puntarenas (Costa Rica)	1	1.15
11	Chacabuco (Chile)	1	1.15
12	Manta (Ecuador)	1	1.15
13	Punta Arenas (Chile)	1	1.15
14	Callao (Peru)	1	1.15
15	Pisco (Peru)	1	1.15
16	Ushuaia (Argentina)	1	1.15
17	Puerto Madryn (Argentina)	1	1.15
	Total	87	100

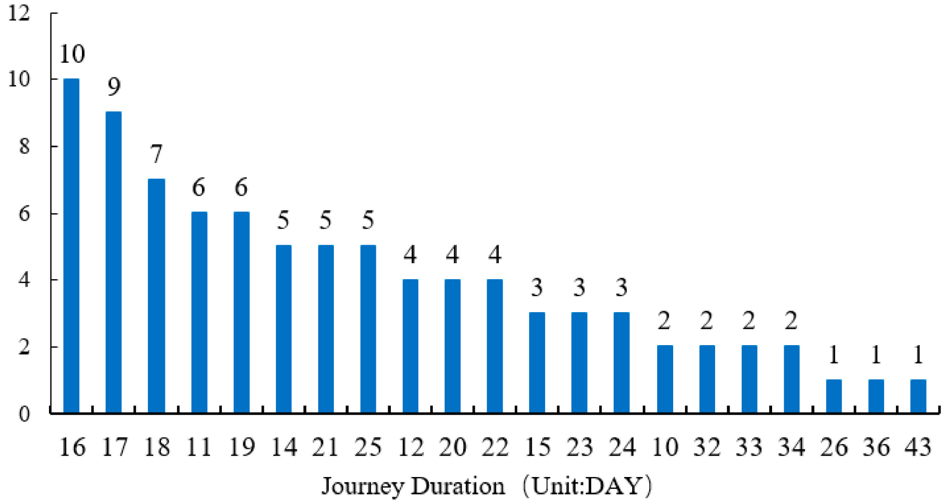

Figure 1. Specific distribution of the trip duration of polar cruise lines.

Currently, the famous brand names of cruise lines operating in China's polar cruise market are Hondius under Oceanwide expeditions, Fram under Hurtigruten, Ocean Atlantis under Albatros Expeditions, and World Explorer under Quark Expeditions, with market shares of 28.24%, 21.18%, 8.24%, and 8.24%, respectively (Table 4). Hondius has performed the highest proportion of the Polar cruise market. Hondius is also an anti-icing 1A + class and has current international recognition as one of the ships with the highest international anti-icing class.

Table 4. List of polar cruise ships in the Chinese market.

Rank	Ship Name	Frequency	Share of Total (%)
1	Oceanwide Expeditions Hondius	24	28.24
2	Hurtigruten Fram	18	21.18
3	Albatros Expeditions Ocean Atlantis	7	8.24
4	Quark Expeditions World Explorer	7	8.24
5	Quark Expeditions Fifty Years of Victory	5	5.88
6	G Adventuresm G Expedition	5	5.88
7	Poseidon Expeditions Sea Spirit	4	4.71
8	Hurtigruten ms Fridtj of Nansen	4	4.71
9	Princess Cruises Coral Princess	3	3.53
10	MSC Poesia	3	3.53
11	MSC Preziosa	2	2.35
12	Holland America Cruises Westerdam	1	1.18
13	Holland America Cruises ms Veendam	1	1.18
14	Poseidon Expeditions Fifty Years of Victory	1	1.18
	Total	85	100

4.1.2. Sale Pattern

The sale pattern of polar cruise products in China is basically described as a combination of 'fly + cruise'. The domestic departure cities of 'fly' are mainly Beijing, Shanghai, Guangzhou, Hong Kong, and Shenzhen. Among them, Shanghai performs the highest frequency with 38.69% (Table 5). According to a report relevant to hot spots of polar tourism in China issued by Fliggy, the tourists from Shanghai account for 65% of the total tourists of the Arctic and Antarctic. This is higher than those from Beijing and Hong Kong.

Table 5. List of departure cities.

Departure City	Frequency	Share of Total (%)
Beijing	62	36.90
Shanghai	65	38.69
Hong Kong	33	19.64
Shenzhen	2	1.19
Guangzhou	6	3.57
Total	168	100

4.2. Chinese Cruisers' Travel Motivation and Restrictions

4.2.1. Travel Motivation

Compared with traditional cruise travel, 'polar + cruise' is a remarkable and indispensable experience segment. The characteristics of the polar cruise are more prominent. The original intention of Chinese cruisers to the Arctic is to appreciate the Aurora, polar bears, and Santa Claus Village rather than enjoy the cruise journey. Cheung et al. [47] addressed that exploring particular wildlife and experiencing nature (e.g., icebergs) are the main driving force for Chinese cruisers to the Arctic. However, cruisers are not concerned about the historical significance of the site. The factors motivating Chinese tourists to cruise in the Arctic are nature, natural reflection, place identity, joining the story, and last-chance experience [48]. However, climate change concerns will encourage cruisers' travel motivation for a last-chance experience [49]. This implies that the effect of climate change may influence the travel patterns and planning of Chinese tourists. There will be an increasing trend for Chinese tourists visiting the Arctic in the forthcoming years.

4.2.2. Travel Restrictions

The first travel restriction is the effect of the product price on travel desire, taking the two well-known domestic tourism websites (i.e., *C-trip* and *Tongcheng*) quotations as illustrative examples. The prices of products for the Arctic and Antarctic cruise tourism range from 50,000 yuan to 250,000 yuan. This discourages tourists from polar cruise tourism. Additionally, international and national policies will contain considerations regarding rigorous environmental protection. This is difficult to balance with the supply and demand sides of the development of the polar cruise tourism market. In 2009, 28 Antarctic Treaty Consultative countries agreed to impose mandatory restrictions on the size of cruise ships and the number of cruisers in Antarctica to reduce the negative impact of human activities on the Antarctic environment. These restrictions pertaining to prohibit cruise ships carrying more than 500 cruisers from docking in Antarctica, allow one cruise ship berth at each location in Antarctica and forbid less than 100 tourists ashore each time.

5. Conclusions

The Chinese cruise market in the Arctic region is expanding. However, it still encounters potential challenges that need to be resolved in the future. The existing hierarchy of polar cruise products needs to be improved, and cruise lines require some breakthroughs. Therefore, the future polar cruise tourism market can make full use of the relevant resources, integrate and cooperate with the global cruise tourism market, improve its characteristics, and analyze the existing and potential needs of tourists. To this end, it can continuously design and implement the possible cruise routes to bring a unique cruise tourism experience in terms of polar natural landscapes and animals.

China's polar cruise tourism market fails to perform with a clear focus. Most cruisers perceive it as an approach to realize polar tourism even if the number of Chinese engage in polar cruise tourism is not less. Additionally, current publicity strategies tend to show and market polar tourism itself. Therefore, it is necessary to expand the existing marketing efforts further and design innovative marketing methods to address the cruise attributes of the polar cruise tourism market. This can encourage cruisers to retake polar cruises.

The contradiction between the continuous expansion of the polar cruise tourism market and the threat of the polar ecological environment is a critical issue. Under this impact, the polar cruise tourism market may sway and out of global ecological considerations, the development and promotion of the polar tourism market should be carried out carefully and seriously. Therefore, various stakeholders should seek to capture the dynamic changes of relevant policies timely and follow up with the needs of the tourist group simultaneously to make adjustments in a timely and reasonable manner. As such, the interests of tourists (the demand side) and cruise lines (the supply side) are maximized accordingly.

This paper provides a general understanding of Chinese cruisers' travel constraints, preferences, and behavioral intention to the Arctic region. However, this study did not conduct a large-scale survey to carry out a comprehensive study and thorough analysis of the Chinese cruise industry to find issues relevant to the industry and cruisers in this region. We also estimate factors of influence of the external environment by using an econometric modeling approach. This will be useful for cruise lines and industrial stakeholders to design and implement cruise shipping strategies in the Arctic region. This should be considered and conducted in future research. This will also be useful in investigating the main features of the Chinese cruise industry and designing different strategies in the Arctic cruise market. To a certain extent, more investigation is urgently demanded to completely investigate the chances and implications of keynotes as the nature and demographics of Arctic tourism change. This study did not consider the logistical chains of cruise passenger movement and cruise ships that perform corresponding cruises. Cruise shipping supply chains is crucial to improving efficient cruise operations and maximizing cruisers' experience. As such, future research should incorporate these issues. Future research may also take into account the models to forecast the development of the sphere of the cruise market and factors of influence of the external environment that affect cruising in this region.

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Developing Countries' Concerns Regarding Blockchain Adoption in Maritime

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Abstract: This paper deals with challenges of implementing blockchain (BC) technology in maritime at developing countries, with a research focus on Montenegro and South Africa. Research design and categories analyzed in the paper are chosen due to the search of relevant secondary literature resources. Selected experts in Information Technology (IT) and maritime from aforementioned developing countries were asked about their perception of BC as disruptive technology, its implementation, and implications on maritime and other industries, through a questionnaire, which contains both quantitative and qualitative parts. The results should give the readers insights into the experts' standpoints concerning rational blockchain adoption in maritime and other industries in developing and transitional economies. The paper is organized into six sections: (1) introduction, (2) literature review on blockchain in maritime, (3) research problem and design, (4) results, (5) discussion, and (6) conclusions.

Keywords: blockchain (BC); adoption; challenges; developing environments

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1. Introduction

Blockchain is a new, transformative technology and business model based on digitalized, shared, distributed, and synchronized ledger. A ledger is comprised of unchangeable, digitally recorded data in blocks. Blockchain enables dealing with smart contracts, recording transactions, and tracking assets in both physical and virtual spaces. Assets can be tangible as money, land, properties, vehicles, etc.; and intangible as energy, patents, intellectual property, copyright, etc. Therefore, blockchain allows an untampered record of transactions over physical and virtual goods [1]. The network nodes within blockchain must validate and approve transactions before their packing into timestamped blocks, which form chains. This requires complex internodes communication and consensus mechanism [2].

Blockchain transforms business from centralized and human-based to a shared, algorithm-based system, which implies a new risk management paradigm [3].

The idea of blockchain arose in 2008 [4], and since then the discipline has been continuously evolving [5]. At the beginning, blockchain was a technological background for bitcoin. As a technology, blockchain can organize bitcoin transactions. Thereby, bitcoin is decentralized peer-to-peer crypto currency for exchanging goods and services virtually through sophisticated cryptography payment mechanisms. Due to the robustness of these mechanisms involved and consensus requirements, a bank as a third party is not needed. The nodes in the blockchain are anonymous, and as such, they can provide more security to other nodes to initiate and confirm the transaction. Besides cryptocurrency applications, blockchain is applied in healthcare, smart energy grids, and supply chains [6]. In healthcare, blockchain serves mostly for tracking medical devices and medicines, using patient biometrics for identification and for measuring and recording patient vitals. When it comes to smart energy grids, there is considerable interest in green and renewable energy sources, including bio-fuels, hydroelectric, solar, and wind energy. The availability of a local energy market implies that participants have a choice of using the local grid when its price is lower than that of the external grid. The blockchain dimension of this includes management of contracts and dynamically determining prices. It offers the opportunities to support the local grid and local renewable energy suppliers.

Besides healthcare and smart energy grids, blockchain finds its application in supply chains that are systems of organizations, people, activities, information, and resources involved in moving products or services from suppliers to customers. Manufacturing and trading of goods is becoming complex due to the increased number of intermediaries between the producer and the final consumer. Globalization and market expansion forced companies to expand their products and life cycle, to meet new markets and requirements [1]. Consequently, supply chain is an ecosystem that involves designing, engineering, manufacturing, and distributing products and services from suppliers to end-consumers worldwide [7].

There is a number of studies that focus on using blockchain technology in various application aspects, but there is no comprehensive survey on the blockchain applications in maritime shipping supply chain [8]. However, recently, Liu et al. [9] dealt with pilot initiatives of blockchain applications and pain points in maritime supply chain. In addition, Tsiulin et al. [10] dealt with block-chain based applications in shipping and port management through literature review towards defining key conceptual frameworks. Zhou et al. [11] considered key challenges and critical success factors (CSFs) of blockchain implementation in the maritime industry, based on studies conducted across Singapore maritime industry.

Since shipping provides mass, low-cost, efficient transportation services, it is the main form of global transportation. Maritime shipping services involve complex partners and deal with numerous transport documents, which can slow down delivering goods from one party to another [12]. Blockchain has been gradually introduced to the maritime shipping supply chain to improve efficiency through the digitalization of maritime shipping records, including keeping real time track of the status of cargos; improving visibility; and reducing consumers' clearance time, costs, and risks.

2. Blockchain in Maritime

Blockchain is designed to record and track transactions. It is very important to understand this technology to become capable to deploy it rationally across maritime clusters for containers tracking and tracing, near-instant logistics adjustments, automated risk management, insurance purposes, and more. Blockchain technology starts to build a block or individual blocks that become a chain, and that is a ledger. One can put information in a ledger, while all involved in the transaction can see that information. If a mistake is made, one has to build a new block that relies on the block before it. If one has multiple transactions, that person can build multiple blocks with multiple people and everybody can see the progression of whatever these multiple transactions are. This is a great advantage from a logistics, accounting, and risk-management perspective to be able to see all these.

One of the pieces behind blockchain technology is so-called Hyperledger. Blockchain programs are built on this platform or framework. The IBM has moved blockchain from in-house to Linux Foundation, and consequently all the code is open source, as a catalyst to move blockchain forward into different industries, including maritime [13]. Danish Maersk uses IBM-established collaboration through the TradeLens platform in 2017 to track container locations, cargo details, trade documents, and sensor readings [14]. The TradeLens offers the oversight control and automated risk management to every stakeholder in the supply chain: beneficial cargo owners, ocean carriers, ports, terminal operators, inland carriers including rail and tracking, shippers, freight forwarders, customs authorities, financial service providers, etc. The TradeLens uses Hyperledger Fabric permissioned blockchain to guarantee the immutability and transparency of trade documents [15]. It has a powerful Application Programming Interface (API) model, but it is easy to use web interface to deliver insights into equipment number, bill of lading number, cargo manifest number, booking number, and all-important information related to the container shipment. Key milestones that include hundreds of events can be followed up and down the supply chain, including near-instant logistics adjustments, so disruptions are kept to a minimum.

Currently, the platform handles 10 million events and more than 100,000 documents every week [16]. It is worth mentioning that there are 120 shipping events types [17]. Within this context, it is important to note that more than $16 trillion in goods are shipped across international borders each year. Approximately 80% of consumer goods used daily are carried out by the ocean shipping industry. By reducing barriers within the international supply chain, global trade could increase by nearly 15%, boosting economies and creating jobs [18].

Legacy data systems and manual document handling cause friction that costs both time and money for business and people throughout the supply chain. The TradeLens enables unprecedented transparency, collaboration, and efficiency in global supply chain. It provides control and management of shipping data and supplies innovative apps to every stakeholder. Access to shipping data and information is managed by the TradeLens' sophisticated permission model at each stage of shipment and provides a blockchain-encrypted audit trail of all critical actions. The TradeLens document store allows documents to be securely stored, viewed, and actioned by various parties. Documents can be uploaded and shared, as either structured or unstructured (scans or PDFs). The last allows information sharing between supply chain partners with disparate IT capacities. The TradeLens platform permits access to documents according to the permission matrix, so the right people can securely manage their supply chain in real-time. It breaks down longstanding data and processing silos that exist among some trading partners and simplifies the flow of documentation, which accompanies every shipment.

3. Research Problem and Design

Through this research study, we aim to collect the information relevant for blockchain adoption in maritime, in two developing countries, Montenegro and South Africa. As a research strategy, we used a survey as a system for collecting information from people to describe, compare, or explain their knowledge and attitudes towards using blockchain in maritime business. This strategy allows us to collect both quantitative and qualitative data and information. The survey was used for exploratory and descriptive purposes as a one-time or one-shot survey. As the survey instrument, we used self-administrated questionnaires that respondents completed on their own via the computer. After data were obtained through questionnaires, they were coded, keyed in, and edited. The questions were conceived after a detailed study of Upadhyay's (2020) study [5] on 'demystifying blockchain'. In addition, we used Rogers (2003), Lee & Kim (2007), Kapoor et al., (2014), Kim & Laskowski (2018), Kapidani et al., (2020), and Zhou et al. [11,19–25]. We applied triangulation of these various approaches and came up with the key dimensions of our questionnaire (Figure 1).

We used both closed and open-ended questions, while we were avoiding double-barreled, ambiguous, leading, and loaded questions [25]. Closed questions were conceived in a way that participants identify advantages or disadvantages of certain blockchain dimensions, and then chose one of the numerical values of Likert scale: 1, 2, 3, 4, or 5. Where, 1 represents the lowest level of agreement or disagreement, and 5 represents the highest level of agreement or disagreement with the statement. The rest of the offered numerical values are respectively in-between these two extremes. The open-ended questions allow respondents to express their opinion in free writing style. The respondents were selected among IT and maritime experts from Montenegro and South Africa. They are from maritime companies, agencies, research organizations, governmental bodies, insurance companies, and universities. They are from executive management level at industry and governmental bodies, and active researchers, professors and lecturers from universities. Responses were received back from 20 experts, of which 10 were from Montenegro and 10 from South Africa. The majority of the respondents from Montenegro are partners or external experts at several ongoing European Commission Horizon 2020 projects, while the respondents from South Africa are from universities and the biggest national multimodal transportation company in the country. After reception, the responses were edited, coded, and analyzed, while the obtained results are presented in the next section.

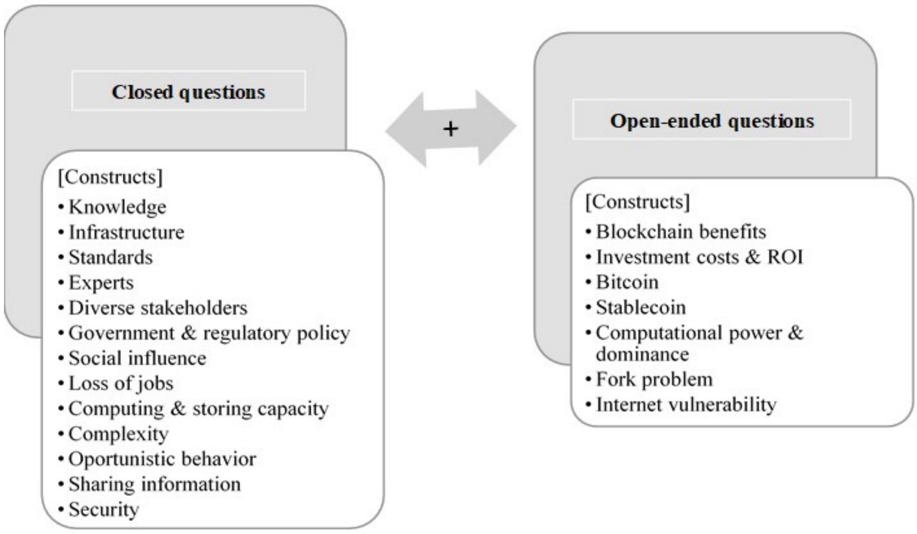

Figure 1. Survey structure and key constructs (Source: Own).

4. Results

All questionnaires sent back by the selected experts were meticulously filled in and there were no missing or 'wrong' data/answers. It was clear that the experts took their roles seriously and understood the importance of the conducted research.

4.1. Quantitative Analysis

The quantitative dimension of the survey analysis comprises average values assigned to "agree" or "disagree" attributes to each considered category within closed-ended questions. The summary of the data analysis is given in Table 1.

Five statements with the highest "agree" and "disagree" assessment rates are categorized in different PESTEL (political, economic, social, technological, environmental, and legal) dimensions, along with their rank (Table 2). The ranks and their connections with PESTEL dimensions will be discussed in the following section.

4.2. Quantitative Analysis

Regarding the qualitative part of the analysis, which was conceived and conducted through seven open-ended questions set around the categories shown in Figure 1, the following issues were considered, and some selected answers given as examples:

(1) Which benefits Montenegro/South Africa might have, for instance, of introducing blockchain solutions in maritime (shipping) industry?
Montenegrin expert: "Allowing tourists to spend their crypto currencies/coins during their stay in Montenegro would bring wealthier tourists. Also, it would bring tourists with crypto savings to spend more money than they planned to spend. The newest technology and tourism always comes together. Bringing wealthy and highly sophisticated digital nomads in and out of high season would bring Montenegro a significant raise in economy. Not to mention other gains like a longer season and employment of local IT experts with a significant raise of GDP. Tracking of tourists'

behavior such as spending and rewarding them with some usable tokens/coins would bring Montenegro tourism, which is dominantly connected with sea, growth, and development."
South African expert: "Blockchain can help by placing the crucial data in one place and creating a unique platform for solution providers, ports, and agents that operate along the supply chain. Allowing tracking cargo in real time using blockchain technology, shipping companies and ports can plan land procedures ahead of time, speeding up terminal works and cutting down costs. Maritime blockchain increases trading safety and transparency. Adopting blockchain technology would elevate the industry to the next level in terms of efficiency and would also impact positively mistakes being done on a daily basis by the personnel in maritime."

(2) It will have lot of cost in terms of time and money to change the existing system, especially when it is an infrastructure. We have to make sure this innovative technology not only creates economic benefits and meets the requirements of supervision, but also bridges with traditional organization, and it always encounter difficulties from internal organization, which is happening now. What do you think accordingly?
Montenegrin expert 1: "Montenegro needs a law that would regulate digital assets, together with crypto exchange and ICO (Information Commissioner's Office) regulation. Tokenizing big tourist investment via crypto would allow the crypto community worldwide to invest in Montenegro future projects."
Montenegrin expert 2: "Definitely, technology is advancing faster than human habits. Are our brains ready for all technological changes, and all that information delivered every day? Adoption is very slow; most of the people do not even use credit cards or e-banking services. It just needs decades, for new digital generations to come."
South African expert 1: "Blockchain technology will transform the maritime industry, as it is still struggling with high costs and a high level of pollution. Blockchain technology can help with both issues, by cutting down administrative costs and providing environment-friendly solutions."
South African expert 2: "Yes, changing from the old system to the new one will have a lot of financial implications for the organizations, but I consider it will be worth it, and ultimately will come with a lot of positives to the traditional organizations."

(3) Use bitcoin for example, the characteristics of the decentralized system will weaken the central bank's ability to control the economic policy and the amount of money, which makes government be cautious of blockchain technologies. Authorities have to research this issue, accelerate formulating new policy, otherwise, it will have a risk on the market. To which extent do you agree with this statement?
Montenegrin expert: "Bitcoin is unstoppable; its network is not censorable. There is no sanctions, no age, gender or any other restrictions. It is free for whole world to use it with the same rules for all. Banks will embrace bitcoin. It will become exchangeable in every bank as the dollar is today. Bitcoin is safeguarded against limitless money printing. It would not replace dollar or euro, but it could be complementary to gold, something as 'digital gold'."
South African expert: "Government will have to look at this system from all different angles in an attempt to find any serious loophole that might come with the system, especially in institutions like banks."

(4) Are you familiar with 'stablecoin'?—Can it assist regarding the previous challenge and in which way?
Montenegrin expert 1: "Local stable coin would bring to Montenegro the newest technology and long-awaited Easy Payment/PayPal-like options, which would for sure boost the Montenegro economy. If most merchants accept stable coin, this will lead to a significant Montenegro economy boost."
Montenegrin expert 2: "Major central banks are running pilot projects with stablecoins. The key question is how money laundering, tax heavens, and corruption will work with stablecoins that are more transparent than current financial systems. I guess we

shall have transparency for ordinary people, while big players will continue to hide their wealth."
South African expert 1: "I am familiar to a limited extent."
South African expert 2: "I am honestly not familiar with stablecoin."

(5) Even though it is an advanced technology, blockchain still struggles with some security issues. For instance, if someone has more than 51% computing power, then he/she can find nonce (number blockchain miners are solving for) quicker than others can, which means that he/she has authority to decide which block is permissible. What is your opinion concerning this issue?
Montenegrin expert 1: "There are several technologies developed, which practically make the 51% attack almost impossible to happen if applied correctly. Still, I always suggest using strong BC projects with huge hash power mining community—POW Blockchain networks, like Ravencoin, BitcoinCash, etc., or some reputable Blockchain netwoks—POS, like Etheraum, Ripple, etc."
Montenegrin expert 2: The 51% is really for smaller coins, but not for bitcoin. This is only a theoretical threat for the bitcoin network, and here is why. Firstly, it will cost billions in equipment to achieve that big hashrate with dubious benefits. The price of bitcoin will go sharply down. Bitcoin mining system is made that way to be more profitable to the honest miner. If an attacker could control the network for a longer period of time, the value of bitcoin would go down to zero, because trust in the bitcoin network would be zero. So, they would manage to get control of a lot of bitcoins that would be worthless. Not to mention worldwide storage of chips, such attack is not even possible right now."
The South African experts consulted from maritime industry were sincere and stated that this issue is beyond their scope of interest and expertise presently.

(6) Another issue is the 'fork' problem. It is related to decentralized node version agreement when the software is upgraded. Then, nodes are divided into old and new ones, and different problems of their mutual communication can appear.
Montenegrin expert 1: "It is democracy, who ever have 51% or more votes, it's a legit version of BC. There will be always one bitcoin, no matter how many times they fork it."
Montenegrin expert 2: "Some argue that while no technology is completely secure, no one has yet managed to break the encryption and decentralized architecture of BC. Decentralized networks can be much or less resilient to shocks, which can affect participants directly, unless careful thought is given to their design."
However, the majority of the consulted respondents are not familiar with this particular issue.

(7) Blockchain uses internet. Does it mean that it is prone at this instance to common internet attacks like 'botnets', for instance?
Montenegrin expert: "BC is not prone to classical botnet attacks, but there are similar ones. Especially when fees for transactions are low, multiple spam attacks are aimed to slowdown transactions and increase fees. Nevertheless, those people are just 'burning' their money, with increased fees; they increase the cost of the spam transactions also."
South African expert: "This is something we live with for all internet services. However, with proper implementation, monitoring, and improvement that would be made on the BC system over time, it would not be prone to any internet-related attacks."

Table 1. The assessments of considered blockchain (BC) adoption dimensions (Source: Own).

Statement	Agree	Disagree
1. The level of awareness and knowledge of BC affects its adoption.	4 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 4 + 5 + 4 + 4 + 5 + 5 + 4 + 4 + 5 + 4 = 9.30	-
2. The BC adoption is affected by the availability of the infrastructure and functionality to integrate and interoperate within and across the business ecosystem.	1 + 5 + 5 + 3 + 5 + 5 + 5 + 3 + 5 + 5 + + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 5 + 4 + 5 = 9.10	-
3. Standardization and ensuring smooth interoperability is necessary, otherwise, BC can make things difficult instead of making them easier.	4 + 3 + 4 + 3 + 5 + 5 + 5 + 5 + 4 + 5 + 5 = 4.30	2 + 5 + 1 + 3 + 3 + 2 + 3 + 5 + 5 = 3.44
4. The BC adoption is affected by the availability of skilled and expert resources.	1 + 5 + 4 + 4 + 5 + 5 + 5 + 5 + 5 + 5 + + 5 + 5 + 5 + 4 + 4 + 3 + 5 + 4 + 4 + 3 = 8.60	-
5. The BC adoption is affected by a large number of stakeholders, with different mind-sets, organizational culture, and working habits.	3 + 4 + 4 + 5 + 3 + 4 + 4 + 4 + 4 + 4 + +4 + 5 + 5 + 4 + 3 = 3.80	1 + 1 + 1 + 2 + 1 = 1.20
6. The BC adoption is increased by favorable government and regulatory policies.	5 + 3+5 + 4 + 2 + 4+5 + 2 + 5 + 5 + + 5 + 5 + 4 + 4 + 5 + 5 + 5 + 5 + 5 + 4 = 8.70	-
7. Social influence positively affects the behavioral intention of using BC.	4 + 4 + 4 + 5 + 3 + 3 + 5 + 2+3 + 2 + + 4 + 3 + 4 + 5 + 2+3 + 4 = 3.53	2 + 2 + 3 = 3.50
8. A perception that BC implementation might lead to loss of jobs can be an obstacle in its adoption.	3 + 1 + 5 + 4 + 5 + 5+4 + 3 + 5 + 4 + + 3 + 4 + 4 + 5 + 5 + 5 = 4.06	2 + 5 + 1 + 5 = 3.25
9. Development in storage, computing, and cloud infrastructure will affect the BC adoption.	2 + 5 + 5 + 5 + 5 + 5 + 5 + 4+ + 4 + 3 + 5+5 + 4 + 5 + 4 + 4 + 4 = 4.35	2 + 2+1 = 1.67
10. The BC adoption reduces opportunistic behavior (opportunistic behavior means maximization of economic self-interest and occasioned loss of the other partners).	1 + 4 + 4 + 3 + 3 + 3+5 + 5 + 3 + 4 + 2 + 4 + 3 = 3.38	1 + 5+4 + 5+5 + 4 + 5 = 4.14
11. The BC adoption is reduced if the information is not shared by the partners, while some stakeholders are hesitant to share information considering it is a competitive advantage.	3 + 5 + 5 + 4+5 + 4 + 5 + 5 + 5 + 4 + + 3 + 4 + 5 + 4 + 3 + 5 = 6.90	1 + 3 + 5 + 1 = 2.50
12. Privacy and security of models and data need to be ensured, as BC technology is still immature and vulnerable.	5 + 5 + 4 + 4 + 3 + 4 + 5 + 5 + 4 + 4 + 5 + 4 + 4 + 3 = 3.9	2 + 3 + 3 + 2 + 1 + 1 = 2.00
13. Blockchain offers a high level of complexity and observability at the same time.	4 + 2 + 5 + 3 + 5 + 5 + 2 + 5 + 3 + 5 + + 4 + 5 + 4 + 4 + 5 + 3 + 2 = 4.47	5 + 4 + 4 = 4.33

Table 2. PESTEL quantitative analysis of selected constructs that affect BC adoption in developing countries: Montenegro and South Africa (Source: Own).

P Political	E Economic	S Social	T Technological	E Environmental	L Legal
Respondents "Agree"					
* Favorable government policies (rank 3)	* Hesitancy of sharing information (rank 5)	Awareness and knowledge about BC (rank 1) Skilled and expert resources (rank 4)	Infrastructure (rank 2)	* Hesitancy of sharing information (rank 5)	* Favorable regulatory policies (rank 3)
Respondents "Disagree"					
	Reduction of opportunistic behavior (rank 2)	Social Influence (rank 3)	Complexity and observability (rank 1) * Standardization (rank 4) ** Ensuring privacy and security (rank 5)	** Ensuring privacy and security (rank 5)	* Standardization (rank 4) ** Ensuring privacy and security (rank 5)

5. Discussion

As a result of summarizing the respondents' quantitative answers, divided into two categories: "agree" and "disagree", the ranks of five constructs assessed with the highest scores for both considered categories are additionally categorized into PESTEL dimensions, while the following can be drawn out:

- The respondents consider awareness and knowledge about BC as a social dimension of utmost importance for BC adoption in maritime and related industries. This is understandable, since knowledge is the biggest asset; the only one that grows with exploitation during the time. Second is infrastructure, which falls under technological dimension. This is reasonable, since without it, BC adoption is practically impossible. Third are favorable government and regulatory policies that fall under political and legal dimensions. This is of crucial importance, since in developing countries like Montenegro and South Africa, the economy and its development are controlled by the government (i.e., the reminiscence of socialism that was an actuality in Montenegro in the past, and which is currently tried to be developed in South Africa). Fourth is experts' knowledge, which belongs to social dimension of PESTEL model, and which is to a certain extent connected with awareness and knowledge, but it can be outsourced in the case of its lack, and under the assumptions that awareness and general knowledge about BC are present. Fifth is hesitancy of sharing information among the parties, and it falls under both economic and environmental dimensions of PESEL. This is understandable, since once BC becomes well-established, the impact of this issue will be reduced, and therefore the related statement is at the last position among selected constructs.
- The highest disagreement is observed regarding the 'simultaneous' presence of BC complexity and observability. The majority of respondents show suspicion regarding this paradox, which is logically understandable. Then, respondents do not agree with the statement that BC will reduce opportunistic behavior. Montenegro and South Africa are countries that for decades have been in a transition, and suffer from the permanent reproduction of crises and injustices. Consequently, their rather skeptical attitude towards this statement is completely understandable. Social influence is in third place. The respondents do not believe that society can impact the implementation of this advanced technology, and this belief is based on their experiences from transitional settings. The statement, which deals with standardization issue, is 'negatively' assessed, but it might be the case due to the experts' belief that standardization must be achieved and that it cannot as such diminish BC key advantages. Ensuring

privacy and security is negatively assessed, as well. This means that some respondents disagree with the statement that BC technology is still immature and vulnerable. Due to their response, one can conclude they believe that BC technology is at a high level of development, that it is less vulnerable, and that it can appear due its complexity and deployment at a global scale. This construct can correspond with technological, environmental, and legal PESTEL dimensions at the same time.

By analyzing the respondents' open-ended questions set around the constructs: BC benefits, investment costs, bitcoin, stablecoin, computational power and nodes' dominance, nodes interoperability, and internet vulnerability, we synthesized the following:

- Montenegrin experts see benefits in adopting BC for the cruising industry, mostly in terms of easier payment, attracting tourists, increased revenue, distributed development of cruise tourism, etc. Furthermore, due to the experts' opinions, BC could have an application in the management of passengers' flows, market analysis, provision of advanced software for cruise industry needs, etc.
- South African experts express positive attitudes in a way that BC can help by placing the crucial data in one place, while creating a unique platform for IT solution providers, ports, agents, freight forwarders, insurance companies, etc., that operate along the supply chain. The BC allows tracking cargo in real time, while shipping companies and ports can plan land procedures ahead of time, speeding up terminal work and cutting down costs. They believe that maritime BC increases trading safety and transparency. Due to their opinions, adopting BC would elevate the industry to the next level in terms of efficiency and affect it positively in terms of reducing the number of human errors.
- Regarding the costs of introducing BC infrastructure and impediments on changing organizational habits, the experts offered different opinions, but commonly, they believe it should be a part of a much needed and inevitable digitalization process. Changing from the old system to the new one will have many financial implications for the organizations, but ultimately it will come with many positives.
- Concerning the question of the central national banks as a regulatory body, Montenegrin experts see benefits, but in general agree that Montenegro central bank is the commercial banks' control body, rather than central bank. Montenegro does not have its own currency and no reason to consider decentralized crypto currencies as competition to other monetary flows. Of course, experts agreed Montenegro needs digital assets, crypto exchanges, and ICO regulations, which would disable eventual money laundering, frauds, or terrorist financial attacks. On the other side, South African respondents see government as the only entity that can put things under control. In general, South African eyes are usually directed towards the government as a central authority that can assist in solving key economic and social problems in the country.
- When it comes to stablecoin, computational power of BC, nodes interoperability, and cyber security, few Montenegrin experts are familiar with these topics, since they are involved in the EU projects, or work as external experts for foreign maritime institutions, or as adjunct professors at foreign universities. However, the lack of technological knowledge is commonly present in South Africa and Montenegro as countries in transition for more than 30 years. Therefore, strengthening technological knowledge transfer (not only ready-made technology) among developed and developing countries can assist considerably.

6. Conclusions

This paper presents the results of literature review regarding BC adoption in general and in particular in maritime industry and business. The literature sources are scarce and dominantly focused on extensive literature review with few papers that concern concrete applications and related issues. In this study, we screened the opinions of several experts from Montenegro and South Africa as developing countries, concerning the attempt to adopt BC rationally. The experts in general agree with the suggested benefits of BC examined through the quantitative part of the study. However, some oscillations in their assessments are noticed, but commonly there is an agreement with assumed benefits of BC implementation in maritime. The observed oscillations mean uncertainty due to the lack of knowledge and experience in blockchain implementation in emerging maritime economies. Through the qualitative part of the questionnaire sent to the experts and later analysis of their responses, we noticed again differences in opinions, which we considered in the discussion. The presence of lack of knowledge and confidence when it comes to some concerns has been noticed, as well. Due to our opinion, the first world countries have been planning and developing BC technology, while the third world countries need to invest more time and money in acquiring knowledge in this technology and respected organizational changes to become credible to determine the right directions for implementing this technology rationally, to protect their national interests, and ensure sustainable development. In this regard, closer communication with developers of this technology would be necessary, as well as exploring needs and preferences of the developing environments, more rigorously, longitudinally, and through larger polls.

Limitations and Recommendations

Since we collected only 20 survey responses, further research should include in-depth interviews or a survey upon a larger poll of experts and deeper discussion on the respondents' assessments, comments, and suggestions. In addition, following investigations in the field should include experts from other developing and transitional countries (besides Montenegro and South Africa), including longitudinal studies, too. The majority of consulted respondents are not familiar with botnets, how they can affect BC, and how such attacks can be prevented. Few are familiar with stablecoin, computational power, and nodes compatibility issues. Therefore, further investigations, building new, and transferring existing knowledge, primarily on BC technological, and then on political, economic, social, environmental, and legal dimensions are needed in developing countries.

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The Coevolutionary Process of Maritime Management of Shipping Industry in the Context of the COVID-19 Pandemic

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Abstract: This study investigates how international organizations, International Maritime Organization (IMO) member states, and associate members have embarked on maritime management (MM) measures to address dire situations in the context of the COVID-19 pandemic. It explores the evolution of MM practices from international organizations, IMO member states, and associate members to ensure the resilience and sustainability of the shipping industry. Corpus linguistics was employed as a computer-assisted method to assess a large number of naturally occurring texts. Circular letters from international organizations and member states listed on the IMO website from January 2020 to July 2021 were curated and built into three corpora. Through corpus linguistic analysis of circulars from three different crisis phases (Pre-/early-crisis, Crisis in progress, Post-COVID-19 crisis phase), we discovered an MM progression mechanism developed between stakeholders in conjunction with the post-crisis period. The study presented the "MM-as-process" vision to emphasize the time-varying dynamic nature of MM development during the disruption.

Keywords: crisis management; maritime management; circular letter; corpus linguistics; coevolution

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1. Introduction

The COVID-19 pandemic has significantly impacted the global shipping industry, causing a severe crisis [1–4]. United Nations Conference on Trade and Development (UNCTAD) has calculated that the amount of international seaborne trade fell by 4.1% in 2020 [5]. Over the pandemic period, shipping demonstrated its reliability and resilience as one of the most economical and efficient modes of transportation. The international supply chain did not suffer significant disruptions. However, seafarers struggled to work on board, and their health and safety were seriously threatened. It was estimated that about 400,000 seafarers were waiting to either be relieved or join their ships. Thanks to the cooperative efforts of the international community, such as international organizations, member countries, the data was reduced from 400,000 to 200,000 [6]. With so many seafarers as front-line workers awaiting rescue, the humanitarian crisis at sea continues to grow.

Although the COVID-19 pandemic continues to bring crisis and uncertainty to the shipping industry, IMO, member states, associate members, and relevant international organizations have been active in issuing circular letters providing maritime management measures to assist shipping stakeholders in coping with adversity. From January 2020 to July 2021, IMO issued 352 circular letters on pandemics covering a variety of matters to minimize the impact of pandemics on international shipping by providing comprehensive guidance and advice to member states and the shipping community shown in Figure 1. In January and February 2020, IMO issued three circular letters. Subsequently in March and April, 20 and 68 circular letters were sent by member states, respectively, showing a dramatic increase, which shows that IMO plays an important leadership role. In addition, the number of maritime proposals submitted by member states is shown in Table 1. In this regard, it is possible to explain to some extent the performance of member states to fulfill their obligations. It is unprecedented in the history of IMO to issue so many circular letters in less than two years dealing with the subject of the pandemic.

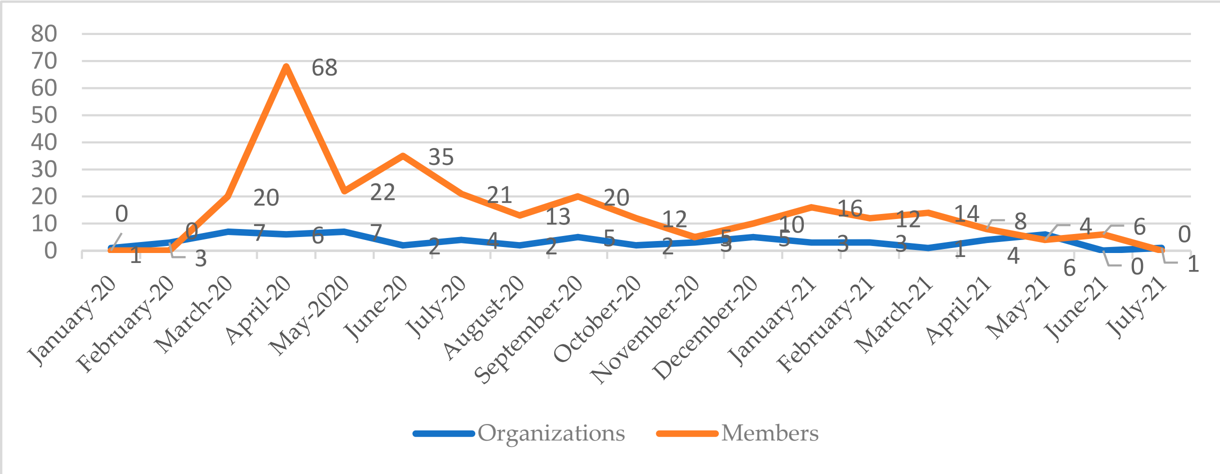

Figure 1. Time and quantity of circular letters from member states and international organizations.

Table 1. Number of maritime proposals from member states (more than 5).

Member States	No.	Member States	No.
The Republic of Italy	19	The Kingdom of Sweden	6
The Republic of Panama	17	The Republic of the Union of Myanmar	6
The People's Republic of China	10	The Republic of Turkey	6
Philippines	10	India	6
The French Republic	9	The Democratic Socialist	5
The Russian Federation	9	The Kingdom of Spain	5
Saint Vincent and the Grenadines	9	The Argentine Republic	5
The Islamic Republic of Iran	6	The Republic of Kiribati	5
The Republic of Azerbaijan	6	-	-

Recently there have been studies on cruise management [1–3], ship inspection [4], Corporate Social Responsibility (CSR) of hotels [7], and air transport emergency strategies [8,9]. However, few articles have examined maritime management in the shipping industry from the perspective of maritime proposals. Research on maritime management is extensive, and most of them conceptualize it as an event or a cause/consequence [10–13]. This line of research focuses on maritime accidents [14], Port State Control (PSC) inspections [4,15], and the marine environment [16]. This static vision of traditional maritime management is essential because it lays the core foundation for future research. However, as we delve further into the empirics raised in the current project study, maritime management is a dynamic and time-varying strategic response to crises.

IMO has issued 352 circulars in one year and a half, all of them on the subject of COVID-19, which was unprecedented in history. It is relatively common to study texts such as maritime accident investigation reports [17], CSR reports [18], and news releases [9], but maritime circulars have not been studied. It is, therefore, an innovation to use textual analysis to analyze maritime circulars. This research endeavors to tackle the aforementioned research gap by examining the evolution of maritime management during the explosion of the shipping industry and emphasizing the process perspective of maritime management. It seeks to answer how the shipping industry adapted its maritime management practices to assist stakeholders in addressing adversity during the different phases of the disaster. This study introduced theories of crisis management and organization resilience and adopted the research methodology of corpus linguistics [19] to evaluate a vast amount of textual data (i.e., circular letters) collected from the IMO website [19]. The research contributes not only in its ability to illustrate how the IMO was able to motivate efforts to minimize the impact and damage of the epidemic on the sustainability of the shipping industry but also in examining the circumstances that contributed to the crisis and how organizations were able to respond to different phases of the situation. More importantly, as we uncover the coherence between the pandemic's influence and the shipping industry's responses to alleviate the difficulties faced by stakeholders, we construct new modeling that highlights the coevolution of maritime management by stakeholders. Maritime management theory has been continuously improved during the development of the shipping industry. Maritime management theory has been continuously improved during the development of the shipping industry. Based on the process view of the crisis, this study proposes a new research direction—maritime management-as-process [20].

The rest of the study is organized as follows. Firstly, theoretical background on crisis management, organization resilience, and maritime management and framing are presented. Secondly, the research methodology is determined based on the procedure and type of data collected. This paper applies a corpus linguistic approach to obtain text data from IMO's website. In order to study the evolution of maritime management, this paper divides the pandemic into three phases: Pre-/early-crisis, Crisis in progress, Post-COVID-19 crisis phase. Thirdly, findings are presented based on keywords for quantitative analysis and concordance for qualitative research, mainly around the evolution of maritime management measures at different stages of the process. Finally, conclusions are drawn based on theoretical and practical implications, contributing new insights to the literature.

2. Theoretical Framework

2.1. Crisis Management

The definition of crisis management is "a set of factors designed to combat crises and to lessen the actual damage inflicted by a crisis" [21]. There are two significant types of literature related to this field of study: crisis as an event and crisis as a process [20]. From the crisis-as-event perspective, one cannot thoroughly plan for a crisis event due to the inability to consider the probability of potential risks [22]. This event-centered research paradigm facilitates the analysis of the consequences of the crisis [20]. The crisis-as-process approach emphasizes the importance of pre-event, in-event, and post-event crisis management [20]. In this process approach, "a crisis is considered to be a long incubation process that manifests itself suddenly under the influence of a precipitating event" [23]. Based on the research theme, this study takes a view of the crisis as a process, analyzing the evolution of the crisis and the actions taken by IMO. On this view, crisis management is understood to be "managing attention to 'weak signals' of crises-in process, in-event organizing, and post-event actions to protect a system and (when necessary) bring it back into alignment" [20].

Two critical properties impact the view of how to manage a crisis. First, crises contain multiple phases. Recognizing how organizational systems are affected by adversity (and thus how organizations respond to adversity and gain resilience) facilitates coping with the complexity of managing crises within an organizational context [24]. Secondly, there are complex relationships among stakeholders that provide severe challenges in dealing with crises [25]. Organizations must constantly adapt and adjust their operational models and practices to achieve resilience utilizing a range of resource endowments to enhance their renewed ability to respond to crises [20].

2.2. Organization Resilience

In 1973, Holling in Canada first introduced the concept of resilience, which falls under the umbrella of ecology. His research concluded that ecosystems are resilient and adaptive [26]. The concept of resilience has spread from ecology into other fields, such as supply chain [27], maritime safety [28], Non-Governmental Organizations (NGO) sustainability [29], etc. Resilience has three main primary properties [30]: (1) The quantity of change that an organization can withstand without changing its structure and function in the face of external pressure. (2) The ability of an organization to maintain its state in the absence of external interference. (3) The degree to which the organization can learn and adapt in the presence of external disturbances.

As maritime transport is a complex system, the concept of resilience is firstly introduced to study maritime safety due to the limitations of safety regulations and risk management to ensure the safety of shipping [28]. A study examined the contributing factors and performance outcomes of resilience in maritime companies from a relational perspective [31]. The outbreak has caused disruptions to the supply chain and has had a severe impact on the normal functioning of goods worldwide. In the context of the epidemic, resilience allows IMO to continue to provide core functionality by proactively determining a response strategy that reduces the impact of disruptions while returning to the original state [32].

2.3. Maritime Management

Maritime management involves employing and maneuvering human, financial, technical, and natural resources associated with the sea, maritime navigation, shipping, port development, and coastal protection [10]. Strategic maritime management is defined as the field of strategic maritime management that deals with the major intended and emergent initiatives taken by general managers on behalf of both owners and stakeholders, involving utilization of resources, to enhance the performance of maritime organizations in the global maritime environment [13]. Maritime traffic management is a process of information exchange and cooperation. It improves safety and sustainability by optimizing the maritime transport chain [11]. Strategic maritime management and sea traffic safety management contribute well to safeguard stakeholders in the shipping industry and optimizing the maritime logistics supply chain. The targets of maritime management include the crew, the ship, the cargo, the shipowner, the maritime authorities, and the relevant international organizations, who are a community of interest.

In this crisis, maritime management played an essential role for the shipping industry in terms of (i) the ability to manage crises and (ii) the ability of interventions to influence collective and individual performance and effectively enhance crisis response. The epidemic has affected the sustainability of the shipping industry and posed a challenge to maritime management. IMO provides the organizational security for maritime management and has a leading position in the shipping community. It is therefore important to derive strategies for the evolution of maritime management by studying maritime proposals.

This study integrated a theoretical framework through theoretical explanations of crisis management, organization resilience, and maritime management (see Figure 2). First, the shipping crisis triggered by the epidemic is characterized by suddenness and stage, so this paper draws on the process perspective of crisis management. Second, the global logistics supply chain was not significantly disrupted by the shipping crisis, reflecting the organization resilience of the shipping industry. Therefore, the theory of organization resilience is also applied to the project. Third, maritime management involved all aspects of the shipping industry and accompanied the entire process of crisis development. Maritime management can improve crisis management capabilities and enhance the level of organizational resilience. In conclusion, there was no necessary boundary between the three theories, but rather a mutually reinforcing relationship, and together they provided the theoretical support for the study of this crisis.

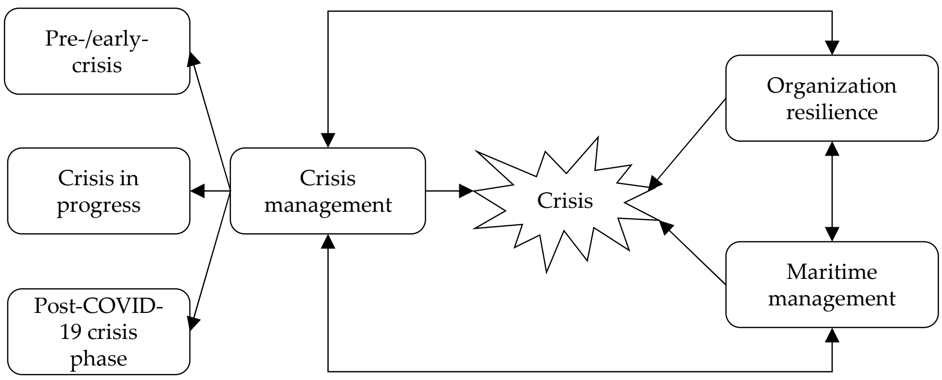

Figure 2. Integrated theoretical framework.

3. Methods

The data includes textual and digital data, and the research object of this paper is textual data. Therefore, this study employed a text analysis approach, which belongs to corpus linguistics [33]. Through a review of the literature, corpus linguistics has been widely applied in interdisciplinary research, such as hoteliers' organizational crisis communication [7], the coevolutionary process of restaurant CSR [34], and strategic crisis response of airline corporations [9]. The corpus has two significant characteristics, a collection of texts stored in electronic databases and naturally occurring texts [35]. Corpus linguistics is the extraction and study of these texts [19,35]. Compared to other research methods, it allows not only qualitative analysis but also quantitative analysis. By quantifying frequency, the analyst discovers the most meaningful words (or other elements) in the text, then studies in detail in their original context. Finally, the most prominent contextual themes are reflected through the form of frequency. Therefore, a platform for interactive communication between frequency lists and qualitative analysis is created.

Corpus linguistics can be used for multiple analyses, and based on the research in this paper, keyword and concordance analyses are the most effective. The comparative analysis of the two corpora is a crucial step in deriving statistically more frequent keywords than expected. One of the two corpora is served as a reference corpus. Next, keywords reveal the most distinctive thematic and stylistic choices in a given corpus and suggest to the analyst which words are most deserving of more in-depth contextual analysis [36]. In the study, the negative keywords indicate overuse in the reference corpus. On the contrary, the positive keywords indicate a relatively high frequency in the target corpus. Concordance analysis allows the researcher to understand the context in which the keywords are located. Concordance analysis also referred to as "keyword in context" concordance, is at the core of the neo-Firthian corpus approach.

Since IMO provides organizational safeguards for the shipping industry, the maritime circular letters related to the COVID-19 listed in the IMO were chosen for data collection. The circular letters were divided into three phrases, depending on the stage of development of the epidemic: (1) The first stage, the dawn of the crisis, January 2020 to March 2020, indicates the pre-/early-crisis. (2) The second stage, crisis in progress, April 2020 to April 2021. (3) The third stage, the post-epidemic era, May 2021 to July 2021. It is worth noting that IMO urged member states and authorities in May 2021 to prioritize seafarers' vaccinations. These circular letters were then built into three corpora: Stage 1 Corpus (January 2020 to February 2020, 4 circular letters, 3342 words), Stage 2 Corpus (March 2020 to April 2021, 331 circular letters, 715,785 words), Stage 3 Corpus (May 2021 to July 2021, 17 circular letters, 41,562 words). The specific descriptions of the three corpora are shown in Table 2. Since LancsBox has a powerful corpus processing function, this study utilized it to perform keyword analysis and concordance analysis [37]. Additionally, stop words, international organizations, and country names were removed from further analysis in order to focus on the lexical patterns and to reduce bias from the sampled data, respectively. In addition, stop words and other irrelevant symbols were removed from this study to focus on linguistic patterns and minimize bias in the sample data.

Table 2. The specific descriptions of the three corpora.

Phase	Files	Tokens	Types	Lemmas
Stage 1	4	3342	822	779
Stage 2	331	715,785	51,479	50,425
Stage 3	17	41,562	6433	6027

4. Findings

4.1. Keyword Analysis

Positive and negative keywords can be derived by comparing the Stage 1 Corpus and the Stage 2 Corpus, the Stage 2 Corpus and the Stage 3 Corpus. These keywords were derived based on the Log-Likelihood significance test, which can reveal the characteristics and focus of the text at different stages. Since the three corpora were of various sizes, they were standardized using relative frequencies with a 99.99% confidence ($p < 0.001$). The two corpora were compared and analyzed to identify positive and negative keywords. Due to space concerns, some representative keywords were listed, as shown in Tables 3–6. The positive keywords and negative keywords characterized the overall tone of the corpora at different stages.

Table 3. Negative keywords for Stage 2 to Stage 1.

Type	Stage 2		Stage 1		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Infections	0.32	9.13	14.96	1.10	0.08
Healthcare	0.60	6.68	14.96	1.01	0.10
Handwashing	0.07	10.06	8.98	1.05	0.11
Incubation	0.28	8.16	8.98	1.18	0.13
WHO	14.53	1.56	104.73	0.55	0.15
Cough	1.63	5.30	14.96	1.01	0.17
Shipyards	0.27	5.22	5.98	1.05	0.18
Risks	1.90	3.32	14.96	0.63	0.18
Implemented	1.48	2.65	11.97	0.80	0.19
Cooperate	0.41	6.20	5.98	1.05	0.20
Enforcement	0.42	4.14	5.98	1.73	0.20
Fever	2.04	4.44	11.97	1.15	0.23
Convention	6.73	1.70	29.92	1.29	0.25
Endeavor	0.07	10.32	2.99	1.73	0.27
Domestic	0.95	4.85	5.98	1.02	0.28
Trade	3.49	2.97	14.96	1.41	0.28

Note: The negative keywords were arranged from small to large by the statistics.

Table 4. Positive keywords for Stage 2 to Stage 1.

Type	Stage 2		Stage 1		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Crew	42.28	1.84	0	0	43.28
Extension	17.14	1.25	0	0	18.14
Certificate	16.47	1.52	0	0	17.47
Pandemic	14.33	1.04	0	0	15.33
Panama	13.65	4.35	0	0	14.65
Members	13.03	1.14	0	0	14.03
Validity	12.36	1.41	0	0	13.36
Seafarer	11.96	1.68	0	0	12.96
Government	11.46	0.98	0	0	12.46
Authority	11.33	2.13	0	0	12.33
Administration	10.60	1.84	0	0	11.60
Surveys	7.84	2.04	0	0	8.84
Company	7.71	2.52	0	0	8.71
Certificates	30.95	1.18	2.99	1.73	8.00
Extended	6.83	1.51	0	0	7.83
Change	6.79	2.51	0	0	7.79

Note: The positive keywords were arranged from large to small by the statistics.

Stage 1. As shown in Table 3, a large number of crisis-related keywords (e.g., "infections", "healthcare", "handwashing", "incubation", "cough", "risks", "fever") and maritime management-related keywords (e.g., "implemented", "cooperate" "enforcement", "convention", "endeavor", "repair") appeared in Stage 1, indicating that maritime management has functioned. From the "cooperate" perspective, member states, shipping companies, port authorities, and other organizations should cooperate to ensure crew health and supply chain. The "implemented", "enforcement", and "convention" demonstrated the emphasis in the instruments issued by IMO on the impact that the implementation of international maritime conventions would have on the shipping industry. These conventions and regulations included but were not limited to: (1) International Convention for Safety of Life at Sea, 1974 (SOLAS, 1974). (2) International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL, 1973). (3) International Convention for the Control and Management of Ships Ballast Water and Sediments, 2004 (BWS, 2004). (4) International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers, 1978 (STCW, 1978). (5) Maritime Labour Convention, 2006 (MLC, 2006). (6) Resolution A.1119(30), Procedures for port State control, 2017. Moreover, the risk-related keywords reflected the symptoms of infection with COVID-19 and the protective measures that need to be taken. Hence, IMO actively communicated and coordinated to prepare for the crisis in the pre-/early-crisis phase.

Table 5. Negative keywords for Stage 3 to Stage 2.

Type	Stage 3		Stage 2		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Panama	0.24	4.00	13.65	4.35	0.08
Inspection	0	0	4.39	2.52	0.19
Survey	0	0	4.23	2.60	0.19
Registry	0	0	2.58	3.62	0.28
Epidemic	0.24	4.00	3.31	4.23	0.29
Accommodation	0	0	2.42	5.07	0.29
Extensions	0.24	4.00	2.47	2.58	0.36
Airport	0.72	4.00	3.67	5.79	0.37
Endorsement	0.48	3.42	2.56	2.63	0.42
Isolated	0	0	1.36	4.53	0.42
Philippines	0.24	4.00	1.84	4.94	0.44
Exemption	0	0	1.22	6.12	0.45
Expire	0.96	2.04	3.34	2.01	0.45
Singapore	0.96	3.15	3.27	6.08	0.46
Certificates	13.96	1.63	30.95	1.18	0.47
Cough	0.24	4.00	1.63	5.30	0.47

Note: The negative keywords were arranged from small to large by the statistics.

Table 6. Positive keywords for Stage 3 to Stage 2. Note: Source: calculated by the authors.

Type	Stage 3		Stage 2		Statistic
	Frequency1	Dispersion1	Frequency2	Dispersion2	
Vaccination	28.39	1.87	0.53	13.62	19.20
Rights	25.98	4.00	0.46	6.22	18.47
Vaccine	17.32	3.98	0.15	8.74	15.89
Human	26.23	3.85	1.12	8.34	12.86
Cruise	28.39	3.90	1.58	7.52	11.40
Roadmap	4.57	2.75	0.07	10.39	5.21
Logistic	1.92	2.95	0.03	18.14	2.85
Immunization	1.68	4.00	0	0	2.68
Restart	1.68	4.00	0	0	2.68
Multi-disciplinary	1.68	3.20	0	0	2.68
ILO	6.50	3.67	1.84	4.78	2.64
e-Governance	1.68	4.00	0.04	18.14	2.58
Manufacture	1.68	4.00	0.04	13.29	2.58
e-Certificate	1.44	4.00	0	0	2.44
Guidance	28.39	1.69	11.11	1.93	2.43
Methodology	1.20	3.28	0	0	2.20

Note: The positive keywords were arranged from large to small by the statistics.

Stage 2. With the World Health Organization (WHO) declaring COVID-19 a global pandemic in March, the shipping crisis intensified and officially entered a crisis phase. Unlike Stage 1, Stage 2 was more inclined to the impact caused by the situation and the measures taken by the stakeholders. Table 4 list the keywords that highlight the lexical features of Stage 2. Most of these positive keywords were only overused in Stage 2, which can show the textual characteristics of Stage 2. The certificate-related keywords (e.g., "extension", "certificate", "validity", "certificates", "extended") were particularly prominent, indicating the impact of the epidemic on certificates under the international maritime convention. Why was "Panama" overused in Stage 2 while the other member states did not appear? We may interpret it in the following two ways. On the one hand, Panama issued 17 circular letters, ranking second among member states. On the other hand, vessels flying the Panamanian flag were the most numerous [38], accounting for about 16% of the total number of ships globally, with a total of 7886 merchant ships of gross tonnage (GT) or more [5,38]. Table 5 lists the significantly overused keywords in Stage 2 relative to Stage 3. Table 5 also summarizes the incredibly overused keywords in Stage 2 comparable to Stage 3. When Tables 4 and 5 were analyzed together, the text features of Stage 2 can be synthesized. Keywords that appeared in both Tables 4 and 5 included "extension", "certificate", "Panama". This further explained that the pandemic caused the extension of the certificate, and Panama was a representative of the member states. In addition, the maritime management-related keywords (e.g., "authority", "administration", "surveys", "registry") indicated the measures taken by the stakeholders. In addition, the travel-related keywords (e.g., "change", "accommodation", "airport") were particularly noticeable, suggesting that the outbreak has severely influenced crew travel and change. Compared with Table 4, the keyword themes of Table 5 are more dispersed. It is more suitable that these keywords can be analyzed in-depth in the concordance analysis section.

Stage 3. With inventing the COVID-19 vaccine, IMO called on member states to prioritize vaccination of seafarers, indicating that Stage 3 entered the post-epidemic era. By the end of June, 60 member states and two associate member states were actively fulfilling their membership obligations by issuing declarations recognizing seafarers as key workers, as listed in Appendix A, Table A1, which facilitates their priority for vaccination and medical assistance. Table 6 indicated that "human" and "rights" appeared in both Stage 2 and Stage 3, and more often in Stage 3 than in Stage 2, suggesting that "human" and "rights" have received increasing attention over time. The overuse of "roadmap" in Stage 3 indicated that it functioned as a somewhat guidance for the outbreak. "Risks", "immunization", "restart", "e-Certificate", and "methodology" only occur in Stage 3, implying that they reinforce the textual features of Stage 3. Moreover, "e-Certificate" and "e-Governance" illustrated that electronic offices were more prevalent in Stage 3. International Labour Organization (ILO), the only tripartite United Nations (U.N.) agency that sets labor standards, develops policies, and devises programs promoting decent work for all women and men, appeared 132 times in Stage 2 and 27 times in Stage 3, sufficiently demonstrating that ILO contributed significantly to safeguarding the rights and welfare of the crew.

Based on the keyword analysis in the above three stages, this study divided the keywords in each stage into the following five themes: crisis, crew, ship, organization, and maritime management (see Table 7). Since Stage 1 was early in the crisis, the number of themes was relatively small. As the crisis intensified, four themes emerged in Stage 2 and five in Stage 3. In other words, the evolution of the theme reflected the progression of the epidemic's impact on the shipping industry. The keywords in Stage 1 revealed the signs that preceded the crisis (e.g., "risk", "cooperative", "fever"). The crisis intensified in Stage 2 and reached its peak with serious consequences (e.g., "extension", "validity", "change"). Stage 3 entered the post-epidemic era, where vaccines were invented, cruise ships were ready to restart, e-Governance was facilitated, and the human rights crisis remained a concern (e.g., "vaccine", "restart", "e-Governance", "rights"). The evolution of keywords and themes hence reflected the progression of the epidemic's impact on the shipping industry. The following section of the concordance analysis provided an in-depth analysis based on the themes and keywords of the three stages.

Table 7. Major themes.

Corpora	Themes	Keywords Used
Stage 1	Crisis	Infections, healthcare, handwashing, incubation, cough, risks, fever
	Organization	WHO
	Maritime management	Shipyards, implemented, cooperate, enforcement, convention, endeavor, domestic, trade
Stage 2	Crisis	Pandemic, epidemic, cough, isolated
	Crew	Crew, seafarer
	Organization	Panama, members, government, authority, company, Philippines, Singapore
	Maritime management	Certificate, validity, administration, surveys, certificates, extended, inspection, survey, registry, accommodation, extensions, airport, endorsement, exemption, expire, certificates
Stage 3	Crisis	vaccination, vaccine, roadmap, immunization
	Crew	Rights, human,
	Ship	Cruise, restart
	Organization	ILO
	Maritime Management	Logistic, e-Certificate, methodology, e-Governance

The shipping industry is at a pivotal moment of transformation and upgrading. On the one hand, it faces a shift from supply chain design and globalization models to changes in consumption and spending habits. On the other hand, more attention needs to be paid to building risk assessment and resilience [5]. However, what are the specific aspects of resilience through the circular letters? Next, resilience can be investigated through KWIC (keyword-in-context) (see Table 8). To summarize, the impact of resilience on shipping is primarily manifested in the following three areas: (1) the global economy, (2) the supply chains, and (3) the essential maritime workers.

Table 8. The keyword resilience in circular letters.

Left	Node	Right
international maritime transport to the	resilience	of the global economy at
supply chains to ensure the	resilience	of our national economies
has demonstrated its reliability and	resilience	as one of the most economic
as to shore up the	resilience	and sustainability of supply chains
may exacerbate the health and	resilience	challenges these essential maritime workers
the Shipping Tripartite Alliance	resilience	(STAR) Fund Taskforce to support

4.2. Concordance Analysis

The keywords and themes of the three stages were identified by quantitative keyword analysis. Next, a better interpretation of keywords and themes at different stages was performed based on qualitative consistency analysis. Due to space limitation, the keyword-in-context exemplary statements for the themes were shown in Appendix B, Table A2.

Stage 1. Pre-/early-crisis. IMO issued four circular letters with the subjects of Novel Coronavirus (2019-nCoV), COVID-19—Implementation and enforcement of relevant IMO instruments, as well as Joint Statement IMO-WHO on the Response to the COVID-19 Outbreak. IMO and WHO have made statements on the characterization of COVID-19 (i.e., "PHEIC"), symptoms of infection (e.g., "fever", "cough"), and response measures (e.g., "cooperate") in terms of crisis, crew, and maritime management. IMO has made a definitive determination that COVID-19 was a severe public health challenge that required close cooperation among all member states. What is more, WHO did not recommend any travel or trade restriction, ensuring that the global logistics supply chain was not interrupted. Based on the above analysis, these four circular letters provide direction to international organizations and member states to ensure the sustainable development of the shipping industry.

Stage 2. Crisis in progress. The crisis in the shipping industry continued to worsen as COVID-19 spread globally and culminated in Stage 2. These proposals were mainly focused on crisis, crew, ship, organization, and maritime management. Firstly, member states actively responded to IMO's call to submit maritime proposals, taking into account their circumstances, for example, Panama, the Philippines, Singapore, China, New Zealand, etc. Secondly, some international organizations also played an important role in combatting the pandemic. IMO, WHO, and ILO, and other organizations, issued individual or joint statements on topics covering crew certification, ship certification, healthcare, crew travel, ship navigation, port management, and more. In addition, ICS published two versions of an outbreak prevention and control guide for ship operators. Thirdly, with port lockdown and travel restriction, a large number of seafarers continued to work beyond their contract period, resulting in a severe crew change crisis. On the one hand, the validity of seafarer certificates extended three months due to force majeure provided by MLC 2006. On the other hand, hundreds of thousands of seafarers struggled to work onboard beyond employment agreements and could not be repatriated. There are just as many seafarers who cannot get on board to work and make money to support their families. It has been causing a humanitarian crisis. Based on the above difficulties, IMO also established Seafarer Crisis Action Team (SCAT) to combat the humanitarian crisis caused by crew change. In addition, certain charterers added the "no change of crew" clause in charterparties for their benefit, which seriously undermines the crew's interests and navigation safety. In response, IMO issued statements strongly condemning such provisions and calling on shipowners and operators to reject such clauses.

Stage 3. Post-COVID-19 crisis phase. The "human rights crisis" and "crew change crisis" have attracted a great deal of attention from IMO. A tool used to support human rights due diligence was a positive response to the ongoing crisis. The tool launched by ILO, IMO, UN Global Compact (UNGC), and UN Human Rights (UNHR) includes the following three parts: (1) Measures that need to be taken by cargo owners and charterers with shipping. (2) Additional actions to be taken by shipping suppliers of cargoes. (3) Additional actions specifically for charterers. As we all know, cruise ships have been hit hard by this epidemic, and restarting cruise ships will contribute significantly to the recovery of the cruise economy. To facilitate the recovery of the cruise industry, the European Maritime Safety Agency (EMSA) and the European Centre for Disease Prevention and Control (ECDC) have issued a joint statement guiding the gradual recovery of the cruise industry in the EU, in particular specific operational instructions. ICS launched the Roadmap for Vaccination of International Seafarers, that set out procedures for a program that can be implemented by all stakeholders concerned to facilitate safe ship crew vaccination. When planning the setting up of a vaccination center, it must be ensured that logistic needs can be supported (for seafarers' access and vaccine distribution).

As shown in Appendix B, Table A2, international organizations and member states issued statements regarding epidemic prevention and control, crew and ship certificates, crew change, etc. Through keyword-in-context, we can understand the context in which keywords were located. IMO played a leading role and issued maritime circulars in all three stages. It is worth noting that Singapore released the second edition of the crew shift guide in June. The Philippines made a statement on the extension of SIB and SIRB. China has issued version 5.0 of the Guidelines for the Prevention and Control of the Crew's Epidemic. From another perspective, member states were actively responding to the call of IMO.

Through the analysis of the three stages, the following three patterns can be drawn. First, in terms of crisis, Stage 1 described the symptoms caused by COVID-19. In Stage 2, COVID-19 was identified as a global pandemic and gave comprehensive guidance on isolation and symptoms. In Stage 3, the vaccine was developed, and the crew could vaccinate according to the roadmap. The above characteristics of the crisis process can be explained by using the phased theory of crisis for reference. Second, IMO, WHO and ILO provided an organizational guarantee in dealing with the situation. Member states actively responded to the call of international organizations. They took measures in port state control, crew travel, certificate extension, vaccination, and crew change to ensure navigation safety, cargo operation, and crew rights and interests. Third, in maritime management, the first phase of maritime management focused on stakeholder cooperation and convention implementation, evolved into the second phase of certificate management, ship inspection, and crew travel, and then evolved into the third phase of electronic certificate and electronic government management. This indicated that electronic means contributed to the implementation of maritime management during the crisis phase of the epidemic.

5. Discussion

Based on the above analysis, this paper presented an integrated framework that describes the impact of the three developmental stages of the crisis caused by COVID-19 on the shipping industry and the coevolution of maritime management (see Figure 3). As the crisis evolved, the focus of shipping industry stakeholders' concerns and maritime management measures also changed. In Stage 1, the shipping industry suffered from a weakened organization due to the epidemic, triggering the issuance of four circular letters from IMO, which could impact crew health, ship maintenance, and cargo flow. In response to the COVID-19 outbreak, IMO implemented maritime management measures in response to the emergency and called for increased international cooperation. In Stage 2, the crisis accelerated as the outbreak worsened, and the focus of stakeholder attention shifted from COVID-19 to the crew. As a result of port lockdown and travel restrictions, the crew change crisis emerged and IMO called on member states to facilitate crew change, as required by maritime conventions. During the period, IMO designated seafarers as key workers, which promoted cooperation among member states and relieved the crew change crisis. In Stage 3, the shipping community entered the post-epidemic era as vaccination was developed. The crew change crisis caused a human rights crisis when the crew continued to work onboard beyond their contract period, and other crew who were resting at home could not work onboard. The roadmap has provided route guidance to facilitate safe ship crew vaccination, which shipping companies, maritime administrations, and national health authorities used in liaison with other authorities. Crew immunizations not only alleviate the human rights crisis but also facilitate the functioning of logistics.

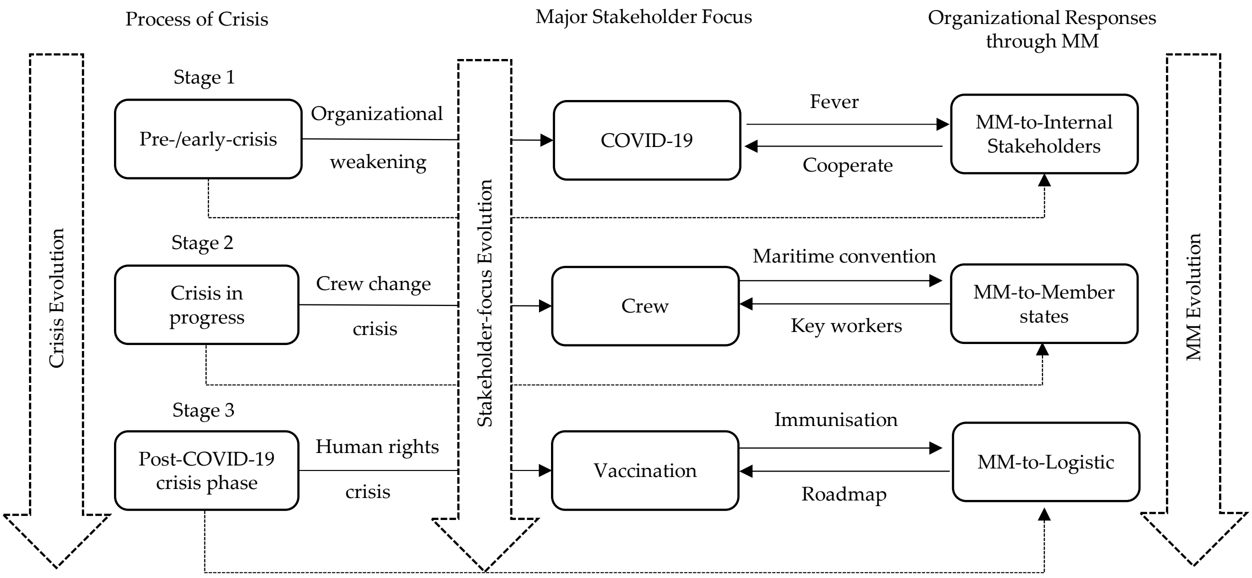

Figure 3. Evolution of Organizational Crisis Response via maritime management (MM).

5.1. Theoretical Implications

The critical contributions of the study to the literature include the following three areas, including crisis management, organization resilience, and maritime management. For crisis management, this paper employed a process perspective and divided the shipping crisis caused by the epidemic into three phases. In particular, we investigated the evolution of the crisis, taking the maritime circulars as a data source. International organizations and member states took maritime management measures in an orderly manner according to the stage of development of the crisis and tried to meet the needs of stakeholders. As shown in Figure 3, as the crisis developed, the shipping industry experienced organizational weakness, then a crew change crisis, and finally evolved into a human rights crisis. The crisis-as-process perspective adopted in this study can explain the number and content of maritime proposals. This laid the theoretical foundation for future studies of shipping crises.

As for organization resilience, the global supply chain was not disrupted by the outbreak, and the shipping industry showed some organizational resilience. Although the epidemic has caused adversity in the shipping industry, the fact that cargo was still moving between the world's ports, that crews are still struggling to change shifts, and that the shipping economy was still slowly recovering, were concrete signs of resilience. The circular letters issued effectively reassured stakeholders in the shipping community and provided policy guidance for the organizational resilience of the shipping industry. In addition, this paper also provided a new research path for the study of organizational resilience through the KWIC analysis of resilience.

For maritime management, IMO takes maritime management measures in the form of maritime circulars, and the maritime management target was changing from the first stage of maritime management corresponding to domestic, to the second stage of maritime management corresponding to member states, to the third stage of maritime management corresponding to logistic. In particular, this study examined maritime management from a process perspective rather than a static one. The focus of different stakeholders' concerns and the impacts caused to varying stages of the crisis evolution process can be effectively analyzed.

In summary, research advances in crisis management, organization resilience, and maritime management can better understand crisis response as a complex and multilateral system. As illustrated in Figure 3, three kinds of evolution co-occurred: the evolution of the crisis, stakeholder concerns, and maritime management objectives. This study primarily emphasized the view that the severe crisis of the epidemic, while adversely affecting crew, member states, and logistics, maritime management was developed as an effective means to help build resilience among stakeholders. Therefore, it also pointed to new directions for subsequent academic research and industry practice on how crisis and maritime management can jointly influence stakeholders and build resilience back on themselves.

5.2. Managerial Implications

The keyword "certificates" was rather impressive. According to the requirements of STCW, MLC, ISPS, and other conventions, there are more types of certificates for crew and ships. The failure of the crew change promptly resulted in expired certificates that threatened crew health and ship safety, which were some of the cascading reactions. Improving maritime management measures to provide lessons for future responses to such crises deserves to be studied next.

The keyword "rights" appeared in both phase 2 and phase 3 and most frequently in phase 3. The absence of regular crew change has caused a severe humanitarian crisis. Although IMO has established SCAT, it can only solve the difficulties of a small group of people, and there are still many more crew members working onboard or staying at home waiting to join their ships. The governments and shipping companies of member countries can provide more assistance to the crew. For example, the government department that manages the crew makes policies to protect crew change and can even offer material and spiritual aid to the crew's family. Shipping companies can consider lifting crew members' wages and strengthening training for crew members on epidemic prevention and control.

An analysis of resilience through KWIC (keyword-in-context) reveals implications for the global economy, supply chain, and maritime workers. Of course, this paper just qualitatively analyzed resilience. Next, a quantitative study of resilience can be conducted to facilitate the economic development of the shipping industry.

Global maritime governance requires the attention and support of every shipping stakeholder. IMO and member states can take this crisis as an opportunity for global governance to explore more effective policies and techniques.

5.3. Limitations and Future Research Directions

Although this study took a longitudinal approach, collecting textual data on maritime circulars from the IMO website, it has to be acknowledged as having limitations. Firstly, in this paper, only maritime circular text data were selected for the study, and IMO website news and shipping company news reports were not considered. Maritime management is comprehensive, and we encourage the acquisition of more data, such as pictures, videos, and text reports, for multimodal research to better explore the evolution of maritime management in a crisis. Secondly, their performance can be assessed in the future based on proposals submitted by international organizations and member countries. This will promote the active implementation of obligations of international organizations and member states and improve IMO's management capacity. Finally, each country has some differences in the number of shipping companies, maritime governance capacity, and regional culture, and some differentiation studies can be conducted in the future.

6. Conclusions

For a better study of the evolutionary process of maritime management, this paper introduced three theories of crisis management, organizational resilience, and maritime management. It integrated them into a theoretical framework, which laid the theoretical foundation for analyzing the results. IMO is an international non-governmental organization that aims to protect the marine environment, safeguard the safety of navigation, and protect the interests of seafarers. During this crisis, crew members have made a massive contribution to the sustainability of the shipping industry as front-line workers, and IMO has recognized them as key workers. Maritime circulars are a critical way for international organizations and member states to release information, with 352 IMO circulars issued cumulatively from January 2020 to July 2021. LancsBox is semi-automated corpus processing software that can analyze unstructured text data. In this paper, maritime circulars were divided into three segments (Stage 1, Stage 2, Stage 3) to study. The keywords of each stage reflected the impact of the epidemic on the shipping industry. In other words, the keywords in each stage can reflect the evolutionary process of maritime management. Based on the above theoretical and analysis results, we presented an innovative "Evolution of Organization Crisis Response via Maritime Management", shown in Figure 3. The stakeholders in the shipping industry have responded positively to this crisis to keep the supply chain from significant disruptions. In addition, we can take this opportunity to improve the revision of maritime conventions. For example, MLC can further increase the provisions to protect the health of the crew. Predictably, the epidemic will not end in the short term, and it will continue to affect the shipping industry. Finally, this paper further improves the theoretical connotation of maritime management and provides a new research idea for future global maritime governance.

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Appendix A

Table A1. List of member states and associate members that have designated seafarers as key workers.

Europe	Asia	Americas	Africa	Middle East	Oceania
Azerbaijan Belgium Croatia Cyprus Denmark Finland France Georgia Germany Greece Ireland Italy Moldova Montenegro Netherlands Norway Poland Portugal Romania Russian Federation Slovenia Spain Sweden Turkey United Kingdom	Bangladesh India Indonesia Japan Myanmar Philippines Republic of Korea Singapore Thailand	Bahamas Barbados Brazil Canada Chile Dominica Jamaica Panama United States Venezuela (Bolivarian Republic of)	Egypt Gabon Gambia Ghana Kenya Liberia Nigeria South Africa	Iran (Islamic Republic of) Lebanon Saudi Arabia United Arab Emirates Yemen	Kiribati Marshall Islands New Zealand
Associate Members					
Faroes	Hong Kong (China)				

Appendix B

Table A2. Keyword-in-context: exemplary statements for the themes.

Corpora	Themes	Concordance Lines
Stage 1	Crisis	1. Avoid close contact with people suffering from acute respiratory infections such as with fever, cough, and difficulty breathing. (IMO) 2. In case of symptoms suggestive of acute respiratory illness either during or after travel, travelers are encouraged to seek medical attention and share their travel history with their healthcare provider. (IMO)(WHO) 3. Perform frequent handwashing, especially after direct contact with ill people or their environment. (IMO) 4. Infection from humans to humans may occur during the incubation period (before persons show signs of sickness). (IMO) 5. The purpose of this circular is to provide information and guidance, based on recommendations developed by the World Health Organization (WHO), on the precautions to be taken to minimize risks to seafarers, passengers, and others on board ships from novel coronavirus (2019-nCoV). (IMO)(WHO)
	Organization	1. With the information currently available on novel coronavirus, WHO advises that measures to limit the risk of exportation or importation of the disease should be implemented, without unnecessary restrictions on international traffic. (IMO)

Table A2. *Cont.*

Corpora	Themes	Concordance Lines
	Maritime management	1. In particular, flag state authorities, port state authorities and control regimes, companies and ship masters should cooperate, in the current context of the outbreak, to ensure that where appropriate, passengers can be embarked and disembarked, cargo operations can occur, ships can enter and depart shipyards for repair and survey, stores and supplies can be loaded, and crews can be exchanged. (IMO) 2. With the information currently available on novel coronavirus, WHO advises that measures to limit the risk of exportation or importation of the disease should be implemented, without unnecessary restrictions on international traffic. (IMO) 3. COVID-19 is a severe public health challenge that requires understanding and close cooperation among all Member States to overcome challenges related to the implementation and enforcement of the relevant IMO instruments. (IMO) 4. The Convention also requires port States to ensure that seafarers on board ships in their territory who are in need of immediate medical care are given access to medical facilities on shore. (IMO) 5. Further, IMO's Convention on the Facilitation of Maritime Traffic (commonly known as the "FAL Convention") states that non-Parties to the IHR shall endeavor to apply the IHR to international shipping. (IMO) 6. The current outbreak originated in Wuhan City, which is a major domestic and international transport hub. (IMO) 7. Following the advice of the Emergency Committee, the WHO Director General did not recommend any travel or trade restriction. (IMO)(WHO)
Stage 2	Crisis	1. On 11 March 2020, the Director-General of the WHO characterized the situation of the COVID-19 outbreak as a pandemic. (IMO)(WHO)(ILO) 2. In countries and at ports where epidemic has been notified, preventive and control measures should be taken in accordance with the local epidemic prevention and control requirements. (China) 3. If the test result is positive, the person must be isolated immediately, and the employer or client must notify the municipality. (Italy)
	Crew	1. Resolving the crew change crisis requires the best efforts of all stakeholders. The elimination of the use of "no crew change" clauses is just one of those efforts. (IMO) 2. Resolution MSC.473 (ES.2). Recommended action to facilitate ship crew change, access to medical care, and seafarer travel during the COVID-19 pandemic, adopted by the MSC on 21 September 2020. (IMO)
	Organization	1. Certificates of proficiency issued by an authorized Maritime Training Center of Panama in accordance with the regulation V and VI of the STCW amended (except those issued under regulation I/2) will be considered valid for a period of three months from its expiry date. (Panama) 2. By the date of this circular letter, the Secretary-General has received 58 notifications from Member States and two from Associate Members that they have designated seafarers as key workers, as listed in the annex. (IMO) 3. More support from the government and digitalization of processes in the supply chain, particularly administrative ones. (IPCSA) 4. For that reason, the Maritime Industry Authority realized the need for a longer extension of validity of the Seafarers Record Book (SRB) or Seafarers Identification and Record Book (SIRB) of Filipino seafarers who could not disembark their vessels and be safely repatriated due to travel restrictions imposed by several countries. (Philippines) 5. In the event that the application for crew change in Singapore is not approved, the company should plan for the crew change to be conducted at other ports that allow crew change. (Singapore)

Table A2. *Cont.*

Corpora	Themes	Concordance Lines
	Maritime management	1. Most IMO instruments contain requirements regarding the extension of the period of validity of a certificate, including SOLAS and MARPOL and associated codes mandatory under these Conventions, as well as the Load Line, BWM, 1 STCW and STCW-F Conventions. (IMO) 2. In a number of instances, e.g., conducting audits, surveys, inspections, and training remote possibilities exist which may eliminate the need to go onboard or reduce the numbers of personnel needing to attend. 3. The good practices carried out by Panama, who has faced a great challenge with the international maritime community as the world's largest ship registry, always paying due attention to the international standards that govern international maritime labor matters, such as the Maritime Labour Convention, 2006, as amended, should be shared and mimicked by other States, and that is what we are asking at this moment. (Panama) 4. Port and coastal States are also encouraged to take a pragmatic and practical approach in relation to these certificate and endorsement extensions, and their acceptance in the exercise of their respective responsibilities. (IMO) 5. While in the current situation renewals of medical certificates may not be possible, exemption from national restriction of movements physicians responsible for medical examination of seafarers should be considered. (IMO)(WHO)(ILO) 6. The effects of this outbreak are having a repercussion with the seafarers whose Certificate/s have expired or will expire soon, where the companies are facing problems because their planned disembarkation cannot be safely completed in ports affected by the outbreak of the Novel Coronavirus. (Panama)
Stage 3	Crisis	1. The designation of seafarers as "key workers" will facilitate their access to the vaccination, since most States are prioritizing essential workers in their national COVID-19 vaccination programmes, in accordance with the WHO SAGE Roadmap. (IMO) 2. The immunization process usually follows three steps: 1. Vaccine preparation; 2. Vaccine administration; and 3. Post-immunization waiting period. (ICS)
	Crew	1. Maritime human rights risks and the COVID-19 crew change crisis: a tool to support human rights due diligence. (IMO)
	Ship	1. The objective of the Guidance is to facilitate a safe restart of operations of cruise ships in the European Union by recommending minimum measures expected to be implemented by all those concerned, while maintaining general safety and security standards. (EMSA)(ECDC)
	Organization	1. Governments have the duty to protect human rights of seafarers and business has a distinct responsibility to respect their rights, UN Global Compact, in cooperation with the International Labour Organization (ILO), International Maritime Organization (IMO) and UN Human Rights, have launched a tool to support maritime human rights due diligence, as set out in the annex. (UNGC)(UNHR)(ILO)(IMO)
	Maritime management	1. Ensuring logistic needs can be supported (for seafarers' access and for vaccine distribution). (ICS) 2. MTI (Maritime Training Institutes) generates an e-Certificate as per existing procedure after appending the digital signatures of the course in charge and the principal. (India) 3. Go to E-Governance tab and click on e-governance. (India)

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