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Cognitive Gap and Correlation of Safety-I and Safety-II: A Case of Maritime Shipping Safety Management

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Abstract: In contrast to the conventional safety management principle, namely, safety-I, which focuses on "what goes wrong", a new-born safety philosophy (safety-II) inspires people to investigate "how and why things go right". In the present study, the cognitive difference and correlation between safety-I and safety-II in the maritime shipping industry are explored and investigated. For this purpose, a questionnaire is administered to survey seafarers and maritime experts, and semi-structured interviews are conducted to collect original data associated with safety-I and safety-II. Then, the data from seafarers and maritime experts are further processed by empirical statistical methods and fuzzy analytic hierarchy process (AHP) methodology. The results show that impacting factors associated with individual aspects are usually accepted as dominant with respect to views of safety-I, while organizational factors are more influential for safety-II, which is essential to developing an organizational resilience capacity. Based on the findings and discussions, potential safety countermeasures that integrate safety-I and safety-II are proposed in this article. The present study discusses the new-born safety-II perspective to elucidate the safety issues associated with maritime shipping operations, which can be seen as the main innovation of this work.

Keywords: maritime industry; safety-II; cognitive gap; correction analysis; safety management

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1. Introduction

Maritime shipping plays a critical role in international merchandise trade in light of the fact that approximately 90% of cargo is transported by ships [1]. Furthermore, according to the prediction made by UNCTAD (United Nations Conference on Trade and Development), international maritime trade will expand at an average annual growth rate of 3.5% over the period of 2019-2024 [2], although this figure could be lower due to the unexpected appearance of COVID-19; nevertheless, the tendency toward increasing international maritime trade will continue. In fact, over the past decade, the total number of vessels and deadweight tonnage (DWT) globally has continued to expand, as illustrated in Figure 1, in which the data comes from the review of maritime transport for 2010–2019 issued by UNCTAD. It is widely accepted that safety issues are combined with maritime trade and that maritime safety issues will become more pressing with increasing numbers of vessels. Therefore, the safety level of navigating ships and the prevention of pollution from ships have become common concerns at national and international levels. For this reason, the International Maritime Organization (IMO) continuously issues conventions, codes, and guidelines to ensure the safety level of maritime shipping operations. For example, as early as the 1970s, the IMO issued the well-known International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) to supervise the unsafe acts of seafarers; in addition, the International Convention for Safety of Life at Sea (SOLAS) was established to provide detailed guidelines for seafarers working on board ships. Apart from the IMO, there are many other international organizations, such as the International Labour Organization (ILO), International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA), and International Association of Ship Classification Societies (IACS), which pay attention to the safety of maritime shipping operations. According to the statistics collected by [3], maritime accidents presented a downward tendency from 2000 to 2012, but the situation is far from satisfactory, according to the "safety and shipping review 2019" issued by [2], and there were still 2698 shipping accidents in 2018. The safety of maritime shipping is still a thorny issue that it is urgent to solve.

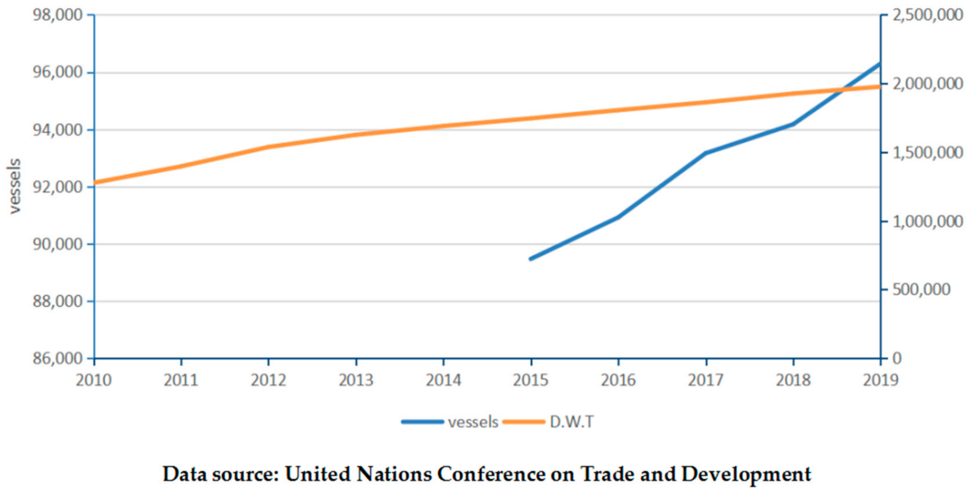

Figure 1. Total vessel number and deadweight of world ship fleet from 2010 to 2019.

Maritime shipping accidents research has changed from being exclusive of naval architects to a being large stage on which knowledge from different disciplines is involved [4]. The factors that contribute to accidents or incidents can be characterized by social attributes or factors associated with techniques; any of these can be the main cause. Therefore, the safety issues of maritime shipping should be solved based on the perspective of complex sociotechnical systems in which the factors associated with techniques and society should be considered comprehensively. In addition, the data from maritime shipping accidents is inadequate for advanced technology, such as big data analysis and artificial neural networks, which encourages scholars or pioneers to explore other methodology to solve the safety issues of maritime shipping. At this point, the perspective of safety-II provides a potential way to solve this problem.

1.1. Related Work

Many studies have been performed to pursue the safety of maritime shipping operations by evaluating and controlling various risks; these are generally regarded as being in the context of the safety-I paradigm. For this purpose, risk identification is the important fundamental work to be accomplished, and the risks involved in the maritime industry can be identified and analyzed according to different principles. It is widely accepted that identifying maritime risk factors based on maritime accident investigation is a good practice, and various accident types have been analyzed for that purpose, such as ship collisions [5,6], grounding [7], fire or explosions [8], as well as maritime operations [9]. At the same time, risk classification based on the ship types is another successful paradigm. In the existing literature, the risks involved in tankers are of concern mostly because serious damage, injuries, and environmental pollution are likely to be caused [10–12]. Additionally, the passenger ships are receiving much attention for the issue of maritime shipping risk analysis, such as in [13,14]. Recently, the risks associated with maritime autonomous surface ships [15] and the ships navigating through the Arctic waters [16] have also been given full consideration. How to evaluate the identified risks is another important issue to be considered, and many scholars developed various methodologies for that approach.

In the early stage, some typical methods have been applied in the maritime industry and proved to be effective, such as human factors analysis and classification system (HFACS), fuzzy fault tree analysis (FTA), cognitive reliability and error analysis method (CREAM), AcciMap [17], and theoretic accident model and processes [18]. Recently, some scholars have attempted to explore the application of big data analysis to maritime shipping risk assessment. The combination of Bayesian networks and other analysis techniques, such as fuzzy theory [19] and data-driven methods [20], is one of the popular methodologies. In addition, artificial intelligence [21] and neural networks [22] have also been successfully applied to evaluate the risk exerted on the maritime shipping operations. According to the existing studies, the risks involved in maritime shipping are characterized by complication, uncertainty, and unpredictability, and therefore, it is urgent to propose a well-designed safety management system (SMS) to control those risks effectively. Many studies have been performed for the establishment of SMS for maritime shipping operations [23–25], which can be integrated with system dynamics to address risks involved in the safety management system [26,27]. In addition, ref [28] presented a typical example that illustrates the process of developing SMS. More recently, he designed a novel maritime safety management system based on system theoretic accident model and process (STAMP), which maps the actual operational needs into the functioning of the SMS [29]. Ref [30] developed an integration model associated with dynamic system and CREAM to identify operational hazards. In fact, the existing studies and practices of SMS are based on the perspective of safety-I, which focuses on the various risks; as a result, the functioning of SMS is still not satisfied, although the safety level of maritime shipping has been improved since the appearance of SMS. Furthermore, almost all of the SMSs do not pay attention to the situated safety knowledge obtained by operators during their activities [31].

The development of the safety-II perspective provides another potential solution for improving the functioning of maritime shipping SMS. The safety-II perspective is characterized centrally by the development of resilience capacity or resilience engineering, which is applied to enable systems in a resilient manner [32]. Based on the principle of safety-II, in the healthcare field, a resilience engineering tool to improve patient safety (RETIPS) is proposed by [33], which is further revised and validated [34], as partly inspired by [35]. Ref [36] takes the taxi service system as an example to analyze the gap between safety-I and safety-II, and some potential advice to improve the organizational resilience is proposed. The OECD [37] issued formal guidelines for resilience systems analysis and proposed a roadmap to develop the resilience capacity. Other successful applications of safety-II are represented by studies for safety issues in the nuclear industry and air navigation, such as [38,39]. In the maritime industry, ref [40] attempted to explain the issue that there is always a lack of regulation compliance even though there is enforcement of the use of safety regulations for fishermens' occupational risks in EU, by the use of a resilience perspective. [41] proposed a solution based on the safety-II perspective to manage the behavior of deck officers during critical operations at sea using simulator-based training. Theoretically, there is considerable potential for the application of the safety-II perspective in the maritime shipping industry, which is widely accepted as a complicated system. Currently, some explorations have been made by scholars, as mentioned above; however, there are still many more studies to be implemented to further clarify the application of safety-II in the maritime shipping industry, which is also the point of the present study.

1.2. Innovative Contributions

In the present study, the objective is to provide a solution for the question of "why are there still so many maritime shipping accidents even though there are existing strict rules and regulations?" The new concept of safety-II, proposed by [32], is introduced in an attempt to analyze and provide a potential solution for the above-mentioned issue. First, the difference between safety-I and safety-II is compared, based on which the factors that contribute to maritime shipping safety are categorized into two groups from the aspects of individual, environment, and organization, as well as techniques. Thereinafter, a comprehensive methodology integrated by expert interview, fuzzy AHP, fuzzy aggregation, correlation analysis, and cross-checking analysis is developed to evaluate the difference between safety-I and safety-II. To address this point, a group of five experienced experts are employed, and a questionnaire survey for seafarers is conducted, the results of which are then used to quantify the aforementioned difference. Finally, some suggestions for the transfer from safety-I to safety-II are proposed based on the results discussion. The salient features of the present study are listed as follows:

The application of safety-II is explored in a maritime shipping safety study in an attempt to propose a solution for thorny safety management issues.

Demonstration of the degree to which the two perspectives, safety-I and safety-II, resemble and differ from each other by comparing indicators that impact the safety of maritime shipping.

The proposed framework is useful for quantifying the difference between safety-I and safety-II, based on which the directions for safety management of maritime shipping can be identified.

1.3. Organization

The remainder of this paper is arranged as follows. Section 2 presents the identified factors that impact maritime safety, which are re-organized based on the concept of safety-I and safety-II. Then, in Section 3, the methodology proposed in the present study is described in detail. Following that, the commonalities and differences between safety-I and safety-II are analyzed and discussed by means of statistical analysis and cross-checking analysis in Section 4, and finally, some suggestions are proposed in Section 5.

2. Identification of Factors that Influence Maritime Safety from the Perspectives of Safety-I and Safety-II

2.1. Concept of Safety-I and Safety-II

Traditionally, safety is defined as a condition where the occurrence probability of adverse outcomes is as low as possible, for the purpose of enabling us to have freedom from accidental events; this definition can be called safety-I. Therefore, the purpose of safety I is to achieve and maintain the state mentioned above or to avoid things going wrong. In practice, the definition of safety based on a safety-I perspective can be seen everywhere. For example, the International Civil Aviation Organization (ICAO) defines safety as "the state in which harm to persons or property is reduced to an acceptable level and maintained at or below an acceptable level through a continuing process of hazard identification and risk management". Theoretically, there is a large amount of literature that could be reviewed for safety issues associated with risk [22]. Thereinafter, under the framework of safety-I, it is critical that the adverse events are analyzed to understand what went wrong and how, to avoid similar adverse outcomes in the future [32]. However, with ignorance of knowledge and cognition about "how things go right", we can hardly overview the "whole thing". In fact, in the maritime shipping industry, "how things go right" has been paid attention to during safety management, and the development and distribution of "best practices" is a typical example. Therefore, the perspective of highlighting the knowledge about "how and why things go right" is labeled by safety-II [41]. According to [32], who first proposed the terms safety-I and safety-II to distinguish the two perspectives of safety, safety-II is "a condition where the number of successful outcomes is as high as possible. It is the ability to succeed under varying conditions. It is achieved by attempting to make sure that things go right, rather than preventing them from going wrong." Under the framework of safety-II, it is the capacity of handling unexpected events that maintains the safety level, and then, it is important to understand the working principle of systems and relationships among events rather than simply looking at the causes of single events [41].

The main differences between safety-I and safety-II are summarized in Table 1. Safety-I argues that things go wrong because of the appearance of failures or malfunctions of specific aspects, such as operating procedures, technology, human factors and organizational factors [42]. As a result, the identification of causes or contributing factors that lead to adverse outcomes is centered under the safety-I framework, which is naturally followed by a series of measures. The approach of safety-II is to some extent a supplementary perspective that focuses on the capability to succeed under various circumstances, which includes the adverse circumstances that cause accidents or events. The main argument of safety-II is to develop the capacity to maintain a successful running system, which could be defined as resilience in some of the literature [16]. Even though there are obvious differences between safety-I and safety-II as presented in Table 1, and they are generally regarded as two distinct perspectives of viewing and achieving safety, they are not mutually exclusive. The safety issue of maritime shipping is complicated, and it involves components of safety-I and safety-II. As is widely known, various guidelines, standards, and rules issued by the IMO are available to provide specifications for maritime shipping operations, based on which the risks that imperil the safety level of maritime shipping can be controlled and eliminated. On the other hand, there is much uncertainty that is involved in shipping operations, and thus, the probability of unexpected events could be high enough to receive attention and subsequently take actions to ensure that things go right. Therefore, the safety of maritime shipping operations is determined by the integration of compliance and resilience, which correspond to safety-I and safety-II, respectively.

Table 1. Overview of the main differences between the safety-I and safety-II perspectives [43].

Aspects	Safety-I	Safety-II
Understanding of safety	Controlling the number and size of things that go wrong	Ensuring that things go right
Performance associated with safety management	Number of accidents or adverse outcomes	Successful case analysis and duration of smooth operations
View of human behavior	A liability, regarding human factors as the main risks	A resource to manage and ordinate technological systems
View of risk	Preventing the occurrence of risk by various measures	Monitoring and managing of the risk factors
Safety management principle	Reactive, taking action after adverse outcomes	Proactive, try to learn and anticipate the development of events
Knowledge basis	Focus on unexpected events, failures and accidents	Understanding success cases and how things go right

2.2. *Factors that Influence Safety-I and Safety-II in Maritime Shipping*

The safe operations involved in maritime shipping can be regarded as a complex socio-technical system that is a determinant for the sustainable development of the maritime shipping industry. There are various impacting factors that influence "things go right" and "things go wrong", which are presented as factors that influence safety in different types of documents, and these factors can be classified based on many different principles. According to typical safety-related studies [44,45], the factors that contribute to safety can be categorized as individual cognition, organizational capacity, and environmental situations. However, the behaviors of individual people and organizations are undergoing notable changes with the introduction of modern technologies, such as artificial intelligence, automation, neural networks, and big data analysis, which are currently applied to solve safety issues associated with maritime shipping [22,46]. Therefore, in the present study, we added the technique factors to the traditional factors system, which is illustrated in Figure 2.

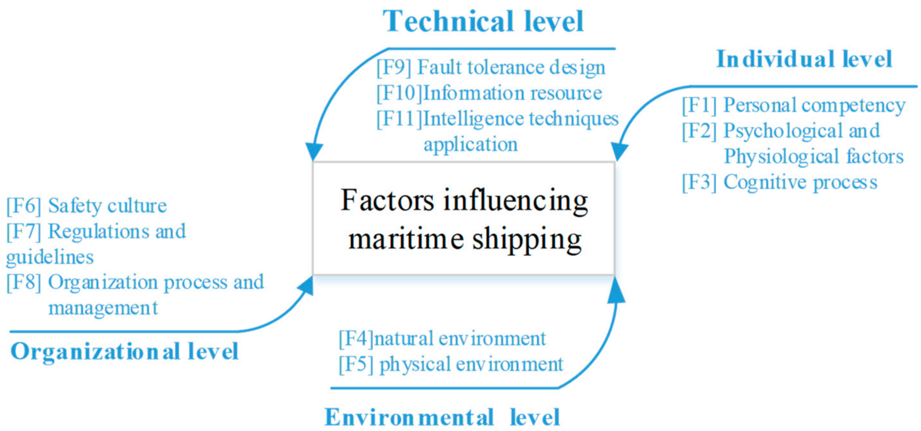

Figure 2. Impacting factors that influence the safety of maritime shipping.

The detailed information for the representative indicators associated with the aforementioned maritime shipping safety-impacting factor hierarchy is summarized in Table 2. The aspect of individuals mainly refers to the human performances or behaviors that affect the safety level of maritime shipping operations, which has been widely discussed and analyzed in a large amount of literature [19,20,47]. Based on these existing studies, we characterized the individual aspect by three groups of indicators, i.e., personal competency, psychological and physiological factors, as well as the cognitive process. According to the perspective of safety-I, these indicators would focus more on the negative aspects of individual people, such as insufficient experience or skills, fatigue, stressfulness, inappropriate decisions, and so on. However, under the framework of safety-II, individual resilience is a critical component for a well-going socio-technical system [32], and individual resilience can be represented by indicators that are easily obtained, such as the best practices, agility, precise anticipation, and emergency responses. Overall, seafarers will be pleased to share their successful experience, while failed experience is not the case. The aspect of organization is associated with administrative hierarchies, management processes, and corporate cultures [48], which is explored by three types of indicators, namely, safety culture, rules and guidelines, organization process, and resource management. Based on the viewpoint of safety I, much attention would be paid to the essential issue, "Why does the organization fail?", which directs the investigators and scholars to analyze the causations, learn from failure cases, and prevent similar accidents occurring again. However, it is difficult to find the causes of organization failure; therefore, the perspective of safety-II is introduced to improve the safety level of the organization by emphasizing the development of a positive safety atmosphere, learning from successful events, and encouraging those positive activities that are useful for safety. As with the representing indicators for the aspect of environment, the factors that influence maritime shipping operations can be associated with the natural environment and physical environment, which can be regarded as the preconditions for the unsafe behaviors of seafarers. Under the framework of safety-I, the challenging meteorological/geographical conditions and risk factors associated with the worksite have been studied by a large number of scholars; however, favorable natural conditions and friendly physical conditions are also given equal consideration according to the perspective of safety-II. The last aspect of maritime shipping safetyimpacting is associated with technical issues, which include the fault-tolerance design, information resources, and intelligence techniques (including automation). Traditionally, it has been regarded that the main feature of safety-I is that the fault design and inadequate information for safety issues would be investigated thoroughly, which would lead to a reasonable solution. At the same time, safety-II argues that the techniques can be applied to improve the safety of maritime shipping by designing fault-tolerant systems and developing an information-sharing platform to reduce the risk factors associated with human action.

Table 2. Description of maritime shipping safety-impacting indicators based on the perspectives of safety-I and safety-II.

Indicators	Description	Specific Explanation	
		Safety-I	Safety-II
Personal Competency	Seafarer competency is assessed based on training, individual experience, knowledge, and professional skill, as well as communication in English [49]	Insufficient experience or professional skills, misunderstanding with each other, insufficient training	The best practices or flexibility presented in an emergency
Personal Factors	Including the psychological and physiological factors that affect seafarer behaviors, especially the psychological factors, which are regarded as particularly important causes leading to occupational accidents [50]	Negative mental conditions, depression or stressfulness; feeling fatigue, stiffness, and/or other physiological diseases/pains	Be positive or optimistic for implementing duty; a high level of agility in daily work
Cognitive Process	Understanding of the safety of maritime shipping, situation awareness, human perception that is useful in addressing an emergency situation	Inappropriate decisions and/or negligence of information, which lead to deterioration of situation until accidents occur	Be able to make prompt and precise anticipation by excellent perception and continuous learning
Safety Culture	Safety culture at different analytical levels affect various unsafe behaviors of onboard ship seafarers [51]	Focus on learning from accidents and/or failures, attempting to prevent accidents by punishment	Emphasis the development of a positive safety atmosphere, and learning from successful cases
Rules and Guidelines	Conventions/laws/standards/guidelines that are widely accepted for maintaining the safety of maritime shipping [19]	Focus on the mismatch between the guidelines or procedures and the actual operational conditions on board the ships	Emphasize the importance of operational manual or standard operational procedures
Organization Process and Resource Management	The safety management of maritime shipping companies, including seafarer training/drilling, and management of violations against rules	Almost all of the rules of a company focus on the violations of seafarers [19], and the training receives less attention	The company encourages activities that are useful for safety maintenance
Natural Environment	Negative natural conditions, including waves, winds, fog, etc., could easily be coupled with other factors, such as unsafe behaviors of seafarers, which could cause maritime shipping accidents [52]	Focus on challenging meteorological/geographical conditions	Both the favorable and unfavorable natural conditions are given full consideration
Physical Environment	Deficient/malfunctioning equipment, or a poor physical environment on board the ship, will put pressure on safe navigation, affecting the ship's performance and increasing the possibility of major safety accidents [53,54]	The potential risk factors associated with worksite conditions receive much attention	Both the friendly and unfriendly physical conditions are fully considered
Fault-Tolerance	Fault tolerance allows a system to continue working properly even with the occurrence of faults [55], which is proven in the maritime industry [56]	Faulty design of a system or equipment, and the technical failures are investigated fully	Favorable technical aspects and design of the system are given the same attention as unfavorable technical conditions
Information Resource	Information resource mainly refers to the navigational information, such as weather report, as well as the navigational publications	Devoted to giving a solution for inadequate communication, incomplete data, missing logbooks, and so on	Emphasize the importance of developing an information-sharing platform
Intelligence Techniques	The introduction of intelligence techniques into the maritime shipping industry is regarded to affect the safety level positively [57]	The application of intelligence techniques can introduce other safety-affecting factors	The application of intelligence techniques can limit the risk factors associated with human

3. Methodology

In this section, an overview of the methodology proposed in the present study is illustrated in Figure 3 with the aim of developing a compatible comprehensive model to assess the impacting factors for maritime safety based on the framework of safety-I and safety-II. The content demonstrated in Figure 3 presents the detailed analysis process, which is summarized as follows:

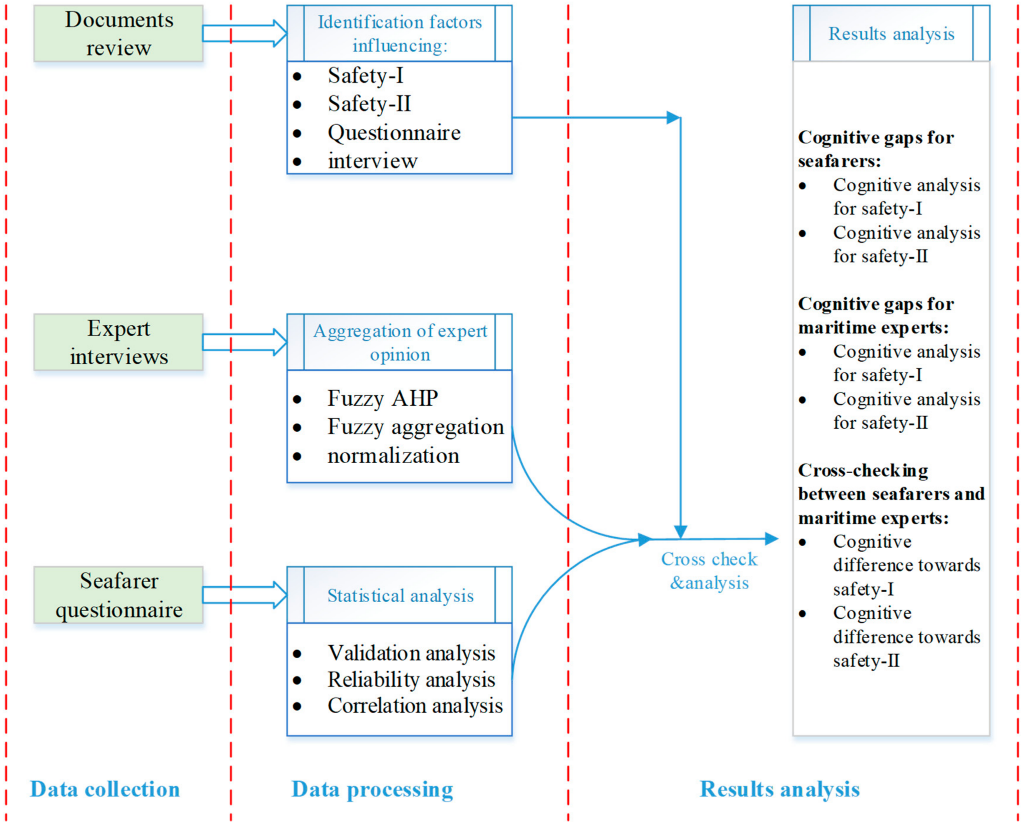

Figure 3. Schematic diagram to analyze maritime safety tendencies.

Step 1—data collection. According to the analysis of Section 2, especially for safety-II, the available information is obviously limited. Therefore, in the present study, we conduct the data collection by means of document reviews, expert interviews, and seafarer questionnaires.

Step 2—data processing. Based on the information obtained from reviews and interviews, the factors that impact maritime safety are identified and then re-organized as contributing factors for safety-I and safety-II. At the same time, a questionnaire is designed after several safety meetings. In addition, expert opinions are aggregated based on fuzzy theory and AHP.

Step 3—results analysis. The results obtained from the aforementioned steps are analyzed by means of correlation analysis (CA) and cross-check analysis, which can be applied to understand the commonalities and differences between safety-I and safety-II.

3.1. Data Collection

The safety-related information associated with maritime activities is limited in the aspects of quantity and reliability, and as a result, the data collection is conducted by reviewing documents, interviewing experts, and implementing a questionnaire.

3.1.1. Analysis of Documents Associated with Maritime Safety

The documents analyzed in the present study are classified into three types, i.e., maritime safety laws and regulations issued by the government and Maritime Safety Administration (MSA); the safety operation manual prepared by the ship management company for safe operations on board the ship; and the accident investigation reports issued by China MSA (China Maritime Safety Administration).

For the first type of document, the maritime safety-related laws, such as Maritime Traffic Safety Law of P.R.C. [58], are the top-level regulations that are applicable for maritime activities. According to these laws, the Ministry of Transport and China MSA issues many regulations to specify the behaviors and activities of seafarers and maritime companies, such as Regulations of the P.R.C. on the Inquiry and Settlement of Marine Transport Accidents. In addition, maritime safety-related international conventions are also referred to during the process of this study, which include SOLAS, STCW, and so on. To obtain an overview that regards the safety regulations of maritime companies, the International Safety Management Code (ISM-CODE) issued by IMO is reviewed in detail during the process of data collection, and then, the researchers of this study are authorized to review a maritime company's shipping safety management system (SMS) developed by ISM-CODE, which provides the researchers with an overview of the "Work as Imaged" in shipping activities. In addition, the collection of maritime accident investigation reports (245 in total) that occurred during 2000 and 2018 in China is conducted in the present study, which can be applied to understand the unsafe behaviors associated with operations on board the ship.

3.1.2. Interviews with Experts and Scholars

The expert elicitation is widely applied in various situations to accumulate specialist opinions for a complicated issue, which is especially suitable to the situation in which the available information is lacking or constrained by physical circumstances [59]. In the present study, the selection criteria for competency experts is expressed as follows:

A heterogeneous expert group is preferred in the present study in which the individual experience of each expert can be considered reasonably, and as a result, the specialist opinions from various viewpoints could be collected and analyzed [60].

With regard to the educational and experience level of the experts in the maritime field, generally, the longer they have focused on maritime safety (academic or practical), the more accurate their intuitionistic judgement is.

With respect to expert familiarity with maritime safety, the experts with experience working on board the ship would be preferred in this study, because they can understand the operations associated with shipping through practical experience [19].

According to the aforementioned selection principle, five experts are employed to be consultants. As shown in Figure 4, all of the five experts are shared with a common experience in the shipping industry; e.g., they have been working as a seafarer on board the ship. The expert group is heterogeneous except for this common experience: two experts are senior scholars coming from academic institutes, two experts are working as marine safety supervisors in MSA, and one expert is the safety manager of a maritime company. Although the careers of the employed experts are diverse, they are familiar with almost every aspect of maritime safety-related issues. The general information of the five experts is summarized in detail in Table 3.

3.1.3. Questionnaire Survey

A questionnaire was designed on the basis of the theory framework of safety-I and safety-II, described in Section 1, while referring to some commonly applied forms designed by [61–63]. The maritime safety-related impacting factors identified in Section 2 are regarded as the guidelines for structuring the framework of the questionnaire. As a result, the preliminary statements in the questionnaire were established, which were then checked by consulting the employed experts before proceeding to the formal survey and interviews.

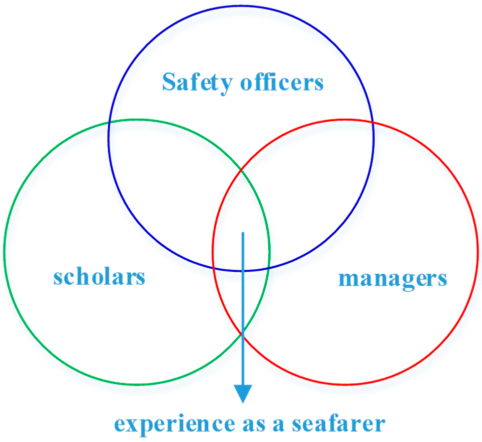

Figure 4. Occupation of the experts employed in the present study.

Table 3. General information associated with experts.

No.	Occupation	Education Level	Certificate Rank	Description
Expert 1 (E1)	Maritime investigator	Master of navigation	Senior captain	He is titled the senior captain and is employed by Maritime Safety Administrative (MSA) as an experienced maritime accident investigator. He has been invited to give a speech in IMO on behalf of China MSA
Expert 2 (E2)	Maritime investigator	Master of navigation	Captain	He has been working on board a ship for nearly 20 years, and at present, he is employed by China MSA as a maritime accident investigator, being responsible for accident investigation
Expert 3 (E3)	Professor in maritime university	Master of marine engineering	Senior chief engineer	Based on his meaningful navigating experience of more than 10 years, he has been working as a scholar to study safety-related issues in maritime shipping, and some of his studies have received attention in the shipping industry
Expert 4 (E4)	Associate professor in maritime university	Doctor of navigation technology	First officer	He has been working on board a ship since 2000 and obtained the first officer certificate before becoming a faculty member in a maritime university. His research interests are focused on safety evaluation for navigating ships
Expert 5 (E5)	Safety manager	Master of navigation technology	Senior captain	He was employed as a safety manager since 2010 in a ship management company, and currently, he is responsible for the safety of cargo ships in his company

At the beginning of the formal questionnaire, the responders were required to identify their positions on board the ship, e.g., master, chief engineer, chief officer; in addition, they were also required to choose the ship types that they have ever had experience on. In the main body of the questionnaire, all of the 44 statements/questions are divided into two parts, which correspond to safety-I and safety-II, respectively. The answers to these statements/questions are presented on a scale of five according to the principle proposed by [64], which ranged from 1=strongly disagree to 5= strongly agree. The respondents are asked to review all of the statements in the questionnaire and to express their judgement by marking a scale from the provided options, which were designed according to a 5-point Likert-like scale. The complete questionnaire can be found in Appendix A of this paper.

In the first part of the questionnaire, there is a total of 22 statements that are focused on the evaluation of the influence of impacting factors on "what goes wrong", which correspond to safety-I. Each impacting factor is associated with two statements, for example, to assess the influence of psychological and physiological factors on maritime safety. The statements are proposed as "Do you have a thorough understanding of unsafe psychological and physiological factors?" and "Do you agree that being distracted will lead to the occurrence of accidents or emergency situations?" In the second part of the questionnaire, all of the 22 statements are designed to assess the influence of impacting factors on "what goes right", which corresponds to safety-II. There are two statements that concern each impacting factor. For example, the influence of the safety culture on the maritime safety can be represented by the following two statements: "As with the reporting culture, do you think it is important to report events to the master or company?" and "Would you like to share your valuable successful or failed experiences with others?"

The questionnaire survey was conducted for different groups. First, the five expert individuals employed in this study, whose general information is presented in Table 1, are asked to give their opinion regarding all of the statements in the questionnaire by the form of interview. On the other hand, the questionnaires were distributed at random to seafarers who were working or have been working on board the ship from May 1 to September 20. The respondents were required to go through all of the statements and give their answers; otherwise, the questionnaire would be considered to be invalid. Finally, we received 105 questionnaires with valid information, and all of the respondents had received their bachelor's degree. The general information on the respondents is presented in Table 4.

Table 4. General information on the respondents.

	Department on Ship		**Rank of Ship**	
	Deck Dep.	**Engine Room Dep.**	**Management Level**	**Operation Level**
Number	64	41	56	49
Percentage	61%	39%	53%	47%

Note: Seafarers at the management level include the captain, chief engineer, first officer, and second engineer; the operation level contains the second officer, third engineer, third officer, and fourth engineer.

3.2. Data Process

3.2.1. Aggregation of Expert Opinions Using Fuzzy Theory

For the operational laws of trapezoidal fuzzy numbers, the reader can be referred to [65], and the relationship between the linguistic expressions of experts and the corresponding fuzzy trapezoidal numbers is shown in Table 5. Although they were at different positions, had different education levels and a variety of experience, it is difficult to quantify the weights of the five experts employed in this study because there are too many factors that influence their weights. Referring to [66], we set the weights for the experts to be equal, e.g., all weights are set to 0.2.

The expert opinions were analyzed when the interviews were completed. First, it is necessary to aggregate the expert elicitation by adapting the defuzzification approach to eliminate any cognitive biases that could be caused by individual experts. Suppose that each expert, $E_i(i = 1, 2, 3, \ldots, n)$, states his or her specific opinions about a certain issue by utilizing a predefined set of linguistic variables. Then, these linguistic expressions can be transferred into the corresponding triangular or trapezoidal fuzzy numbers, which can be processed further until defuzzification is achieved.

Table 5. Linguistic expressions and their corresponding fuzzy trapezoidal numbers.

Linguistic Expression	Fuzzy Trapezoidal Number
Very low	(0,0.1,0.2)
Low	(0.1,0.25,0.4)
Medium	(0.3, 0.5,0.7)
High	(0.6,0.75, 0.9)
Very high	(0.8,0.9,1)

(1) Calculation of the degree of similarity.$S_{uv}(\widetilde{E}_u, \widetilde{E}_v)$ is defined as the degree of agreement for different opinions among experts. Suppose that $\widetilde{E}_u(a_1, a_2, a_3)$ and $\widetilde{E}_v(b_1, b_2, b_3)$ represent two standard triangular fuzzy numbers ($u \neq v$); then, the degree of agreement between $\widetilde{E}_u$ and $\widetilde{E}_v$ can be obtained by

$$S_{uv}(\widetilde{E}_u, \widetilde{E}_v) = 1 - \frac{1}{J}\sum_{i=1}^{J}|a_i - b_i| \quad i = 1,2,3 \tag{1}$$

where J is the number of fuzzy set members; e.g., $J = 3$ is for standard triangular fuzzy numbers and $J = 4$ is for standard trapezoidal fuzzy numbers. Additionally, the greater the values of $S_{uv}(\widetilde{E}_u, \widetilde{E}_v)$, the greater the similarity between experts E_u and E_v.

(2) Calculation of the average agreement (AA) degree for each expert's viewpoints.

$$AA(E_u) = \frac{1}{U-1}\sum_{u \neq v, v=1}^{U} S_{uv}(\widetilde{E}_u, \widetilde{E}_v) \tag{2}$$

where U is the total number of experts.

(3) Calculation of the relative agreement (RA) degree between two types of experts. The value of $RA(E_u)$ for the uth expert can be obtained by

$$RA(E_u) = \frac{AA(E_u)}{\sum_{u=1}^{U} AA(E_u)}. \tag{3}$$

(4) Estimation of the consensus coefficient (CC) for each expert. The value of $CC(E_u)$ for the uth expert can be obtained by

$$CC(E_u) = \beta * P(E_u) + (1 - \beta) * RA(E_u) \tag{4}$$

where the coefficient $\beta(0 \leq \beta \leq 1)$ is introduced to represent the importance of $P(E_u)$ over $RA(E_u)$; namely, the greater the value of β is, the more important $P(E_u)$ is. In fact, when $\beta = 0$, no weight is distributed to $P(E_u)$, which indicates that a homogenous group of experts is employed; for another limit case, $\beta = 1$, and the consensus degree among the various expert viewpoints is adequately high.

(5) Calculation of the aggregated results of the expert viewpoints. The aggregated results, which are denoted by $\widetilde{R}_A$, can be computed by

$$\widetilde{R}_A = CC(E_1) \otimes \widetilde{E}_1 \oplus CC(E_2) \otimes \widetilde{E}_2 \oplus \cdots \oplus CC(E_u) \otimes \widetilde{E}_u. \tag{5}$$

(6) Defuzzification of the aggregated results. The defuzzification of fuzzy numbers is critically important for the application of fuzzy set theory. The center of area (CoA) method is widely used for the defuzzification operation, and it is expressed as

$$X = \frac{\int \mu_M(x)xdx}{\int \mu_M(x)dx} \tag{6}$$

where X represents the defuzzification result, and $\mu_M(x)$ indicates the aggregated membership functions defined for fuzzy triangular and trapezoidal numbers. Therefore, the fuzzy numbers of the aggregated results, denoted as $\widetilde{R}_A(c_1, c_2, c_3, c_4)$ for fuzzy trapezoidal numbers, can be defined by (7),

$$R_A = \frac{\int_{c_1}^{c_2} \frac{x-c_1}{c_2-c_1} x dx + \int_{c_2}^{c_3} x dx + \int_{c_3}^{c_4} \frac{c_4-x}{c_4-c_3} x dx}{\int_{c_1}^{c_2} \frac{x-c_1}{c_2-c_1} dx + \int_{c_2}^{c_3} dx + \int_{c_3}^{c_4} \frac{c_4-x}{c_4-c_3} dx} = \frac{1}{3} \frac{(c_4+c_3)^2 - (c_2+c_1)^2 - c_4c_3 + c_1c_2}{c_4+c_3-c_2-c_1}. \tag{7}$$

3.2.2. Validation of the Questionnaire

The validation of the questionnaire survey is conducted by the validity and reliability tests in the present study. With respect to the validity test, the commonly applied approach is to calculate the KMO (Kaiser–Mayer–Olkin) statistic values and Barrlett's test p-values, which are obtained by the application of the software SPSS.

(1) Introduced by [67], the KMO index has been widely applied to measure the sampling adequacy for proposed factors and to evaluate the effectiveness of the data quantity to conduct valid factor analysis.
(2) Bartlett's sphericity test p-value [68] is usually used to present the correlation among the factors involved in a proposed matrix or an indicator system and, as a result, whether the data quantity is adequate for structure detection can be determined. The lower the p-value is, the more effectively the factor analysis is conducted, based on the data.

The calculated results associated with the KMO index and Bartlett's test p-value, and the evaluation criteria are presented in Table 6. According to the contents of Table 3, the KMO values of all of the four aspects associated with safety-I and safety-II are higher than 0.6, which is set as the criteria to judge the quality of the questionnaire, and the p-value of Bartlett's test is lower than 0.004, which also satisfies the factor analysis requirement.

Table 6. Results of the validity test.

Aspects	Safety-I			Safety-II		
	KMO	p-Value	Number of Extracted Factors	KMO	p-Value	Number of Extracted Factors
Individual	0.7329	0.0002	3	0.8358	0.0001	3
Environment	0.6398	0.0000	2	0.7985	0.0000	2
Organization	0.7012	0.0001	3	0.6937	0.0000	3
Technique	0.7165	0.0000	3	0.8046	0.0002	3

The reliability analysis of the proposed questionnaire is conducted to evaluate the consistency and stability of the data collected from the questionnaire, which was received from multiple sample groups. In the present study, a widely used parameter called Cronbach's alpha [69] is utilized to estimate the reliability by

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K} \sigma^2 Y_i}{\sigma^2 X}\right) \tag{8}$$

where K denotes the total number of questions in the questionnaire, e.g., $K = 44$ in this study. Here, $\sigma^2 X$ is the total sample variance, and the ith observational sample variance is represented by $\sigma^2 Y$. The value of α is varied from 0 to 1; as a criteria, the higher value of α is, the more satisfactory the reliability of the proposed questionnaire. The results of the Cronbach's alpha associated with the questionnaire designed for this study are illustrated in Table 7.

As shown in Table 7, the values of Cronbach's alpha for the indicators structured in various levels are higher than the threshold value of 0.6 [70], which indicates that the questionnaire data satisfies the factor analysis requirement with respect to the consistency and reliability. Based on the results of the validity test and reliability test, it is evident that the questionnaire was designed well and the data collection in this study was well-conducted, which can be used to assess the influence of the impacting factors on maritime safety.

Table 7. Results of the reliability test and evaluation criteria.

Paradigm (Cronbach's Alpha)	Aspects (Cronbach's Alpha)	Indicators	Cronbach's Alpha
Safety-I (0.7298)	Individual (0.7635)	[F1] [F2] [F3]	0.6985 0.7429 0.8013
	Environment (0.7043)	[F4] [F5]	0.7925 0.6616
	Organization (0.7462)	[F6] [F7] [F8]	0.6487 0.8145 0.7848
	Technique (0.6879)	[F9] [F10] [F11]	0.7147 0.6983 0.6871
Safety-II (0.7156)	Individual (0.7468)	[F1] [F2] [F3]	0.8210 0.6853 0.7149
	Environment (0.7043)	[F4] [F5]	0.7362 0.6841
	Organization (0.7524)	[F6] [F7] [F8]	0.7682 0.7712 0.7216
	Technique (0.6853)	[F9] [F10] [F11]	0.6754 0.6620 0.7014

3.3. Data Analysis for Presenting the Results

The data collected from maritime experts and respondents (seafarers) is analyzed by two different approaches, which share the same dataset as the input. In this way, we can effectively investigate the cognitive gap between different groups, i.e., seafarers and maritime experts; at the same time, the cognitive aspect for maritime safety based on safety-II can be obtained from the two groups, which can be applied to develop a new perspective toward improving the safety level of the maritime industry. Thereinafter, collecting the data from the seafarers through the questionnaire survey was followed by a statistical method, which is called Correlation Analysis (CA) [70]. The CA method is a commonly used method to analyze linear correction issues due to the advantage of being less sensitive to the sample size. In the present study, the CA can be achieved with the application of the software SPSS. The data from maritime experts through interviews are further analyzed by the fuzzy aggregation method, which has been proven to be an outstanding method to address the uncertain information involved in the maritime industry [19]. Therefore, the results to be discussed in the present study will be presented as follows:

Statistical analysis of the cognitive aspect with regard to maritime safety according to the viewpoints of seafarers.

Fuzzy aggregation analysis of the cognitive aspect with regard to maritime safety based on the perspective of maritime experts.

Cross-checking for the viewpoints from seafarers and maritime experts is implemented to clarify the gap, which can be utilized to improve the safety level of the maritime industry.

4. Results and Discussion

4.1. Seafarers: Cognitive Transfer of Maritime Shipping Safety from Safety-I to Safety-II

With respect to the cognitive aspect of seafarers on board the ships with regard to safety-I and safety-II, the questionnaire survey is implemented as mentioned above in Section 3.1.3, and after validation, the questionnaire is processed by correlation analysis and normalization. Finally, the results are presented in Table 8. It can be observed that there are obvious cognitive differences between safety-I and safety-II according to the opinions of the seafarers. Based on the perspective of safety-I, the aspects of individuals and techniques, especially the factors associated with individuals are more important for the maintenance of safety, i.e., the risks that lead to maritime accidents mainly originate from daily operations on board the ships, which can be used to explain the establishment of the international conventions of STCW and SOLAS. However, in regard to safety-II, the influence of individual factors is weaker, and the factors associated with the organizational aspect receive a substantial amount of attention; as a result, the role of the organization is emphasized in the process of safety management. In addition, the environment is regarded as the last important aspect according to both safety-I and safety-II, which can be interpreted as the seafarers are satisfied with the prediction of natural conditions.

Table 8. Results of the CA for the seafarers.

Aspects	Indicators	Safety-I			Safety-II		
		Correlation Coefficient	Normalization	Sum	Correlation Coefficient	Normalization	Sum
Individual	F1	0.6848	0.1354	0.352	0.1592	0.0803	0.251
	F2	0.4166	0.0824		0.1026	0.06	
	F3	0.6764	0.1337		0.2433	0.1103	
Environment	F4	0.2355	0.0466	0.17	0.1578	0.0563	0.15
	F5	0.6338	0.1253		0.1900	0.0913	
Organization	F6	0.3286	0.065	0.134	0.2832	0.1245	0.356
	F7	0.0504	0.01		0.2228	0.1029	
	F8	0.2975	0.0588		0.2952	0.1288	
Technique	F9	0.4027	0.0796	0.343	0.1808	0.088	0.243
	F10	0.6087	0.1203		0.2493	0.1124	
	F11	0.7231	0.143		0.0609	0.0425	

The influences of eleven indicators, which represent the four aspects of maritime safety, are illustrated in Figure 5. Based on the cognitive aspects of seafarers working on board ships, under the framework of the safety-I perspective, it is observed that the seafarers are concerned with most of the physical circumstances on board the ships and the operational process, such as the conditions of the mechanical equipment and various cognitive processes for the operations, which are represented by the indicators of "fault tolerance design", "cognitive process", and so on. With the respect of safety-II, the seafarers acknowledge the positive affect of the maritime shipping company, and they argue that the safety culture and organizational process and management are critical factors for maritime safety management. As with the cognitive difference between safety-I and safety-II, it is obviously found that an extreme difference is presented by the attitudes with regard to mechanical equipment and regulations. According to the perspective of safety-I, the seafarers emphasize the fault tolerant design of the equipment and pay less attention to the regulations and guidelines; however, under the framework of safety-II, the seafarers should consider carefully the application of various regulations and guidelines and pay less attention to the mechanical equipment. In addition, both the cognitive process and information resources are emphasized by safety-I and safety-II.

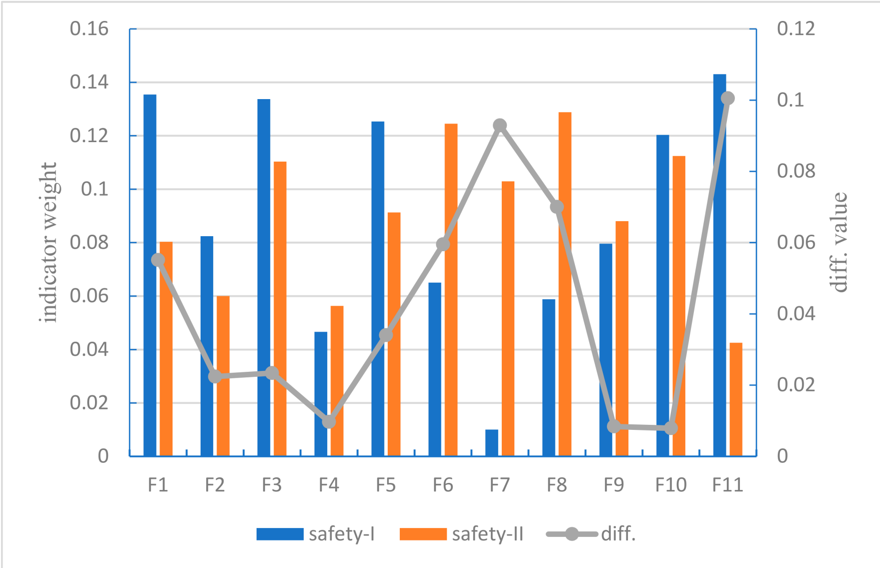

Figure 5. Cognitive difference between safety-I and safety-II for seafarers.

4.2. Maritime Experts: Cognitive Transfer of Maritime Shipping Safety from Safety-I to Safety-II

Based on the FAHP described in Section 3, the opinions of maritime experts employed in the present study are aggregated and normalized, and the results are illustrated in Table 9. It can be observed that the individual is the most important aspect in both safety-I and safety-II, which verifies the importance of human factors for maritime shipping safety management. At the same time, the environments, including the natural environment and physical environment, are regarded as the last important aspect based on the perspectives of safety-I and safety-II. The attitude differences toward the organization and the techniques are presented for safety-I and safety-II. According to the cognitive aspect for safety-I, the influence of the organization is more important for maritime shipping safety management, while the techniques, especially for the application of artificial intelligence, receive much more attention under the framework of safety-II. Therefore, according to the viewpoint of safety-II, the safety level of maritime shipping is largely decided by the management of individual factors and the applications of modern techniques.

Table 9. Results of CA for maritime experts.

Aspects	Indicators	Safety-I			Safety-II		
		Aggregation Value	Normalization	Sum	Aggregation Value	Normalization	Sum
Individual	F1	0.7429	0.1362	0.3640	0.6008	0.1045	0.3114
	F2	0.6326	0.1160		0.6000	0.1043	
	F3	0.6094	0.1117		0.5896	0.1026	
Environment	F4	0.4091	0.0750	0.1210	0.3503	0.0609	0.1199
	F5	0.2508	0.0460		0.3390	0.0589	
Organization	F6	0.6280	0.1152	0.2714	0.5913	0.1028	0.2759
	F7	0.3286	0.0603		0.5255	0.0914	
	F8	0.5235	0.0960		0.4697	0.0817	
Technique	F9	0.2212	0.0406	0.2436	0.6343	0.1103	0.2929
	F10	0.5323	0.0976		0.503	0.0870	
	F11	0.5747	0.1054		0.550	0.0956	

The eleven impacting indicators associated with the four aspects are evaluated, and the results are illustrated in Figure 6. The employed experts argue that personal competency and safety culture are more important to maintaining the safety level according to the content of safety-I, and the function of artificial intelligence is underestimated under the framework of safety-I, which is regarded as the last important impacting indicator. In contrast, the intelligence techniques application is accepted as the most important contributor to achieving the aims of maritime shipping safety management from the perspective of safety-II. Therefore, it is obvious that the impacting indicator of "intelligence technique application" holds the larger difference between safety-I and safety-II than any other indicators followed by the indicator "regulations and guidelines".

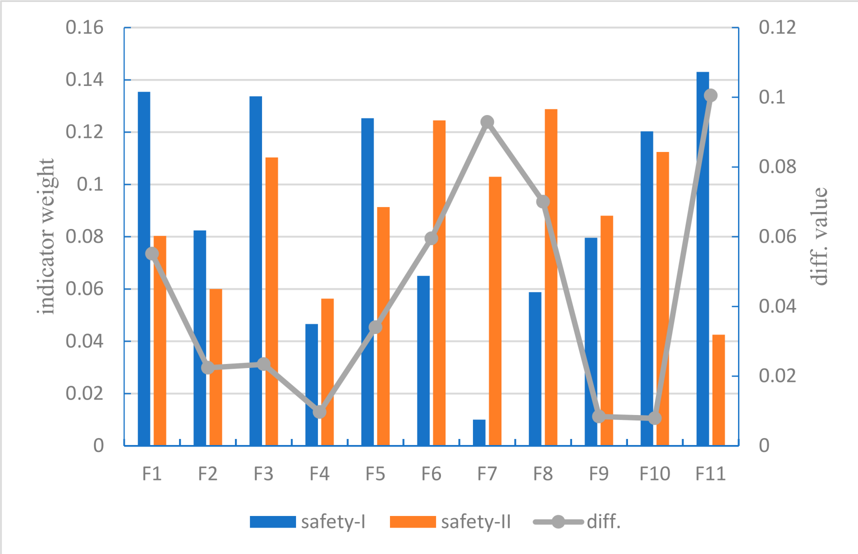

Figure 6. Cognitive difference between safety-I and safety-II for maritime experts.

4.3. Cross-Checking to Develop the Potential to be Safer in the Maritime Industry

The exploration of the differences between maritime experts and seafarers with regard to safety-I and safety-II is critical to establishing an effective solution for maritime shipping safety management, and we bridge the gap between theoretical study and practical application. For this purpose, the cross-checking of the results obtained from maritime experts and seafarers is implemented in this section. Under the framework of safety-I, the cognitive aspects with regard to the impacting indicators from maritime experts and seafarers are compared, and the results are illustrated in Figure 7. It is obviously observed that both the maritime experts and the seafarers unanimously argue the importance of personal competency, which implies supervision toward risk factors associated with individuals is an effective means for safety management according to the views of safety-I. In addition, it is interesting that the maritime experts argue that there is much work to be done in the field of safety culture of maritime shipping companies and psychological and physiological states of seafarers, while the physical environment on board the ships and the mechanical design are of more concern for the seafarers on board the ships. In fact, the impacting indicator that the seafarers are concerned with the most is the operational environment on board the ships; however, the maritime experts, especially the maritime scholars, pay much more attention to the design of the safety management system, which almost agrees with the actual situation. In addition, there is a slight difference with regard to the indicator of "personal competency" and "cognitive process", which are valued by both maritime experts and seafarers; i.e., the situational awareness and human perception are widely accepted as the effective capacity to defend the risk of maritime shipping operations.

The cognitive difference between maritime experts and seafarers working on board ships with regard to safety-II is illustrated in Figure 8. Seafarers on board ships are concerned with the factors that are associated with their operational conditions, the regulations of their company, and the atmosphere where they live and work; specifically, these factors are represented by the indicators of "safety culture" and "organization process and management". However, the maritime experts pay more attention to the application of intelligence technologies in the maritime shipping industry; at the same time, the management with regard to the risk that originates from unsafe actions of seafarers is also of concern by maritime experts, who argue the importance of investigating seafarers' unsafe behaviors. It is interesting to observe that both the seafarers and maritime experts recognize the importance of "safety culture", which is widely accepted as one of the critical components in a safety management system. The most notable differences with regard to safety-II between seafarers and maritime experts are represented by the indicators of "organization process and management" and "fault tolerant design". According to the interviews of maritime experts, the application of intelligence techniques in the equipment on board ships should be further enforced, and most of the emergent situations and maritime accidents are caused by human factors, which motivated the IMO to modify the contents of the convention of STCW to further specify the behaviors of the seafarers. On the other hand, seafarers are confident that their skills and experience are sufficiently competent for their duties on board the ships. Different from maritime experts, the seafarers are concerned more about the safety culture of the shipping company, and they argue that a well-developed safety culture can provide an atmosphere in which the safety level of maritime shipping operations can be promoted.

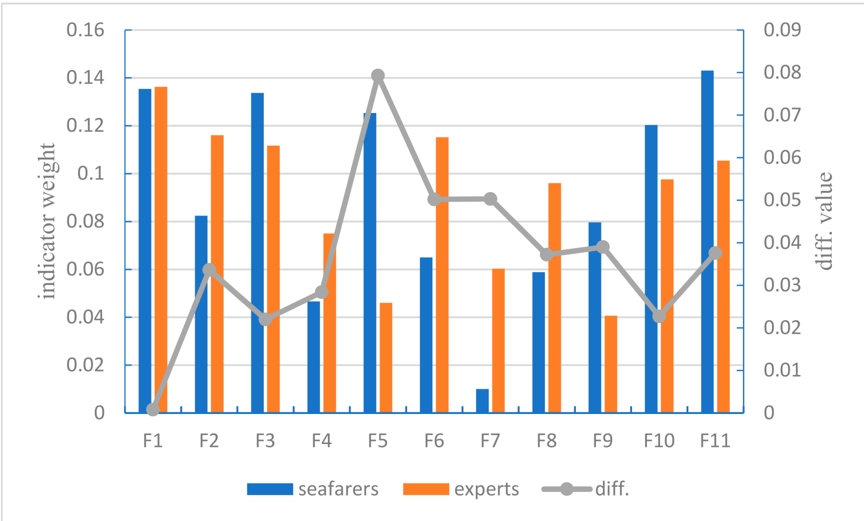

Figure 7. Cross-checking for the cognitive aspect with regard to safety-I of seafarers and maritime experts.

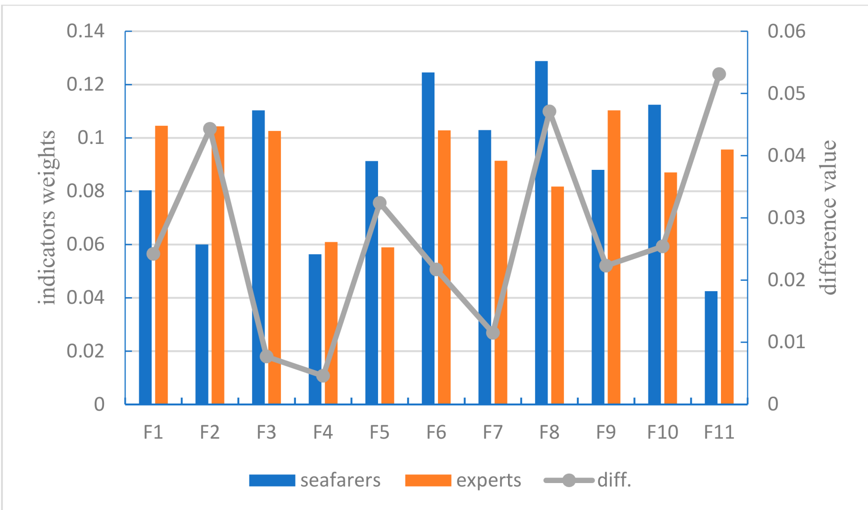

Figure 8. Cross-checking for the cognitive aspect with regard to safety-II of seafarers and maritime experts.

5. Conclusions

In the present study, we explore the application of safety-II in maritime shipping safety, which is regarded as a typical complicated system. Traditionally, the issues of maritime shipping safety are usually solved by observing the principle of safety-I, which centers on the reduction of the risk level. However, the safety level of maritime shipping is not matched with the anticipation of the industry, and therefore, the safety-II perspective is introduced to improve the maritime shipping safety level. Focusing on the principle of "How and why things go right", the safety-II approach aims to identify and characterize the impacting factors that are involved in the successful cases of maritime shipping from a positive perspective. Thereafter, the cognitive differences between seafarers and maritime experts with regard to safety-I and safety-II are investigated by means of a questionnaire survey and fuzzy AHP, respectively. The data collected from seafarers and maritime experts are analyzed and discussed by methodologies, such as correlation analysis, fuzzy aggregation, and cross-checking analysis. The results show that the cognitive difference is obvious the most for the seafarers in the aspects of "regulations and guidelines" and "fault tolerance design" with regard to safety-I and safety-II, and the maritime experts argue that the most salient difference between safety-I and safety-II is represented in the field of "intelligence technique application". Based on the findings and discussions mentioned above, specific safety countermeasures are proposed, as follows.

(1) The integration of safety-I and safety-II should be prioritized to improve the safety level of maritime shipping operations. Actually, the principle involved in the integration of safety-I and safety-II implies that lessons should be learned from both failures and successes. In practice, the information about successful cases is easier to obtain according to the results of the questionnaire survey for seafarers and maritime expert interviews. In addition, safety-II is more useful to developing a well safety culture that is accepted as one of the key aspects of maritime shipping safety management by both seafarers and maritime experts.
(2) Developing and enforcing "best practices". Best practices for various operations on board ships can be regarded as an effective tool for safety management based on both safety-I and safety-II perspectives. On the one hand, the best practice can provide a guideline to defend various risks; on the other hand, the best practice is a type of treasury for successful cases. Therefore, a practical suggestion is that the improvisation cases that originated from on board operations are updated periodically into manuals on board ships and into the training books.
(3) Encouraging data collection and information sharing associated with maritime shipping safety. Data collection is critical for the safety management of a complicated system. Based on safety-I and safety-II, the resources of data are presented as failures/accidents and successful cases, and it should be noted that the data involved in near-miss events are difficult to obtain. Information-sharing is an effective method for diffusing operational skills and experience.
(4) Balancing intelligence techniques applications and maritime shipping safety. The balance between artificial intelligence and safety is an urgent issue to be solved in the near future, which is verified in the present study. The seafarers working on board the ships hold negative opinions with regard to the intelligence techniques, which is reflected in the results of the questionnaire survey, while the maritime experts argue that the function of artificial intelligence is positive in maritime shipping safety management. This finding can be explained by the knowledge difference and education background of seafarers and maritime experts. Therefore, practical advice is proposed in that content about artificial intelligence be added into the training manuals or competency requirements.

As an initial exploration of the application of safety-II to solve the safety issues associated with maritime shipping operations, the present study is characterized by several limitations. First, the cognitive differences between safety-I and safety-II are analyzed and discussed more than their combination, which limited the application of safety-II in the maritime shipping industry. On the other hand, the epistemic uncertainty in the analysis process and the data volume constrained the further application of this study to the maritime shipping company. In addition, the experts employed in the present study and the questionnaire volume can be further improved, which is regarded as a limitation of this study. Therefore, in the near future, an investigation into the combination of safety-I and safety-II should be implemented, and it is necessary to further evaluate the factors that contribute to safety-II and develop practical strategies for the maritime shipping industry. Moreover, with the extensive application of artificial intelligence, the industrial revolution is in progress [71], how safety management 4.0 will impact on maritime shipping safety should be considered for future research.

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Appendix A

Questionnairepart I (for safety I)

Individual level

1. In case of operating the unfamiliar equipment separately, what about the probability for the occurrence of an accident?

2. What about the correlation between the experience and safety operation?

3. Do you have a thorough understanding of unsafe psychological factors and physiological factors? (Including their harm and precaution)

4. Do you agree that being distracted will lead to the occurrence of accidents or emergency situations?

5. Do you agree that many accidents associated with ships are caused by inappropriate emergency actions?

6. As far as you know, to what extent can the negligence of parts of standard operating procedures lead to the occurrence of accidents or emergency situations?

Organizational level

7. Do you agree that the safety level of operations on the ship board can be improved greatly by analyzing the failure cases associated with ship operations?

8. If the company develops punishment measures, do you think that the safety level of the ship operation can be effectively improved?

9. Have you ever experienced an emergency situation caused by being freaking according to regulations or operational procedures?

10. As far as you know, is it a main contributing factor to accidents that some guidelines or regulations are difficult to be implemented?

11. Do the policies and rules focus only on the violation of human behavior?

12. Do you think that training or drilling focusing on accidents is a good way to improve the safety level of the ship operations?

Environmental level

13. According to your experience or as far as you are concerned, is a rough sea the main cause for accidents or emergency situations?

14. Have you ever experienced, as far as you know, a natural environment that can be predicted satisfactorily?

15. Have you ever experienced, or as far as you know, that accidents are caused by faulty design of equipment or systems on board the ship?

16. Do you agree that the emergency situation is mainly caused by technique failure or malfunction?

Technical level

17. If the intelligent techniques are widely applied on board the ship, do you think that the safety level of the navigating activities can be well guaranteed?

18. With the appearance of an unmanned ship, do you agree that the safety issues can be solved thoroughly?

19. Are the logbooks on board the ship reviewed regularly and feedback presented to seafarers, or do you think it is necessary to do so?

20. Do you or your master pay much attention to the information collection of unsafe events?

21. Fault-tolerant design is regarded as a way to be safe; how about the importance of fault-tolerant design to maintain safe operations?

22. In a standard operation procedure, are there any procedures that are designed against accidental operations or incorrect operations?

QuestionnairePart II (for safety II)

Individual level

23. As far as you know, do you agree that the personal experience is critical to implementing daily operations on board the ship?

24. In case of emergency, is it necessary to allow the crew to take actions that could be inconsistent with the present rules?

25. As far as you are concerned, compared with skill, what is the importance of agility to be a competent seafarer?

26. In the description of being competent, is it necessary to emphasize further the importance of physiological health?

27. If the learning material is available on hand, do you tend to have continuous learning from successful cases?

28. Have you ever had a sense of pride if your work goes smoothly during your board on ship?

Organizational level

29. As with the reporting culture, do you think that it is important to report events to the master or company?

30. Would you like to share your valuable successful or failed experience with others?

31. Do you think that the operational manual or standard operations procedures are important to maintain the safety of your ship?

32. If a procedure is available to submit your advice to the safety department or maritime administration, would you be willing to do so?

33. If the ship or master is authorized further, do you think that the ship will be safer?

34. If the company pays much attention to the smooth operation and successful cases, do you think it will be beneficial to improve the safety level of the ship?

Environmental level

35. In case of good natural conditions, or when the natural conditions are well predicted, do you think that the occurrence probability of accidents will decrease greatly?

36. As far as you know, how about the positive correlation between the natural condition and human error on board the ship?

37. Have you ever found any outstanding design for safety issues and kept them in mind?

38. If the manufacturers are ready to listen to you, would you like to give your feedback?

Technical level

39. If the safety-related information is available, do you think that big data analysis will be helpful to improving the safety level of the ship?

40. If the artificial intelligence techniques are applied to marine equipment, can the reliability of the equipment be improved effectively?

41. Do you agree that the safety level can be improved by sharing information, which is presented as best practices?

42. With the information management and application, do you agree that the data collection and database establishment is one of the most difficult issues to be solved?

43. Do you think that a well-designed fault tolerant arrangement can be helpful to developing well behavior?

44. Compared with the control and management of human error, is the design of fault tolerance more effective for improving the safety level?

References

1. ICS. The International Chamber of Shipping Annual Review. 2018. Available online: http://www.Icsshipping:docs/default-source/ICS-Annual-Review-2018/annual-review-2018.pdf?sfvrsn=8 (accessed on 11 September 2020).
2. Allianz Global Corporate & Specialty. Safety and Shipping Review 2019. 2019. Available online: https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf (accessed on 11 September 2020).
3. Eliopoulou, E.; Papanikolaou, A.; Voulgarellis, M. Statistical analysis of ship accident sand review of safety level. *Saf. Sci.* **2016**, *85*, 282–292. [CrossRef]
4. Luo, M.; Shin, S.-H. Half-century research developments in maritime accidents: Future directions. *Accid. Anal. Prev.* **2019**, *123*, 448–460. [CrossRef] [PubMed]
5. Chauvin, C.; Lardjane, S.; Morel, G.; Clostermann, J.-P.; Langard, B. Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. *Accid. Anal. Prev.* **2013**, *59*, 26–37. [CrossRef] [PubMed]
6. Chai, T.; Weng, J.; Xiong, D.-Q. Development of a quantitative risk assessment model for ship collisions in fairways. *Saf. Sci.* **2017**, *91*, 71–83. [CrossRef]
7. Mazaheri, A.; Montewka, J.; Kujala, P. Towards an evidence-based probabilistic risk model for ship-grounding accidents. *Saf. Sci.* **2016**, *86*, 195–210. [CrossRef]
8. Li, J.; Huang, Z. Fire and Explosion Risk Analysis and Evaluation for LNG Ships. *Procedia Eng.* **2012**, *45*, 70–76. [CrossRef]
9. Şakar, C.; Zorba, Y. A Study on Safety and Risk Assessment of Dangerous Cargo Operations in Oil/Chemical Tankers. *J. ETA Marit. Sci.* **2017**, *5*, 396–413. [CrossRef]
10. Goerlandt, F.; Montewka, J. A probabilistic model for accidental cargo oil outflow from product tankers in a ship–ship collision. *Mar. Pollut. Bull.* **2014**, *79*, 130–144. [CrossRef]
11. Akyuz, E.; Celik, E. A fuzzy DEMATEL method to evaluate critical operational hazards during gas freeing process in crude oil tankers. *J. Loss Prev. Process. Ind.* **2015**, *38*, 243–253. [CrossRef]
12. Hsu, W.-K.; Lian, S.-J.; Huang, S.-H. Risk Assessment of Operational Safety for Oil Tankers—A Revised Risk Matrix. *J. Navig.* **2017**, *70*, 775–788. [CrossRef]
13. Spyrou, K.; Koromila, L. A risk model of passenger ship fire safety and its application. *Reliab. Eng. Syst. Saf.* **2020**, *200*, 106937. [CrossRef]
14. Xie, Q.; Wang, P.; Li, S.; Wang, J.; Lo, S.; Wang, W. An uncertainty analysis method for passenger travel time under ship fires: Acoupling technique of nested sampling and polynomial chaos expansion method. *Ocean Eng.* **2020**, *195*, 106604. [CrossRef]
15. Fan, C.; Wróbel, K.; Montewka, J.; Gil, M.; Wan, C.; Zhang, D. A framework to identify factors influencing navigational risk for Maritime Autonomous Surface Ships. *Ocean Eng.* **2020**, *202*, 107188. [CrossRef]
16. Ma, X.; Zhou, Q.; Liu, Y.; Liu, Y.; Qiao, W. Security of the Arctic route from the resilience perspective: The ideal state, influencing factors, and evaluation. *Marit. Policy Manag.* **2020**, 1–14. [CrossRef]
17. Wiegman, D.A.; Shappell, S.A. Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification system(HFACS). *Aviat. Space Environ. Med.* **2001**, *72*, 1006–1016. [CrossRef]
18. Leveson, N. A new accident model for engineering safer systems. *Saf. Sci.* **2004**, *42*, 237–270. [CrossRef]
19. Qiao, W.; Liu, Y.; Ma, X.; Liu, Y. Human factors analysis for maritime accidents based on a dynamic fuzzy Bayesian network. *Risk Anal.* **2020**, *40*, 957–980. [CrossRef]
20. Fan, S.; Blanco-Davis, E.; Yang, Z.; Zhang, J.; Yan, X. Incorporation of human factors into maritime accident analysis using a data-driven Bayesian network. *Reliab. Eng. Syst. Saf.* **2020**, *203*, 107070. [CrossRef]
21. Łosiewicz, Z.; Nikończuk, P.; Pielka, D. Application of artificial intelligence in the process of supporting the ship owner's decision in the management of ship machinery crew in the aspect of shipping safety. *Procedia Comput. Sci.* **2019**, *159*, 2197–2205. [CrossRef]
22. Qiao, W.; Liu, Y.; Ma, X.; Liu, Y. A methodology to evaluate human factors contributed to maritime accident by mapping fuzzy FT into ANN based on HFACS. *Ocean Eng.* **2020**, *197*, 106892. [CrossRef]
23. Akselsson, R. Safety culture on board six Swedish passenger ships. *Marit. Policy Manag.* **2005**, *32*, 159–176. [CrossRef]
24. Lappalainen, F.J.; Kuronen, J.; Tapaninen, U. Evaluation of the ISM Code in the Finnish shipping companies. *J. Marit. Res.* **2014**, *9*, 23–32.

25. Boström, M.; Österman, C. Improving operational safety during icebreaker operations. *WMU J. Marit. Aff.* **2016**, *16*, 73–88. [CrossRef]
26. Di Nardo, M.; Madonna, M.; Murino, T.; Castagna, F. Modelling a Safety Management System Using System Dynamics at the Bhopal Incident. *Appl. Sci.* **2020**, *10*, 903. [CrossRef]
27. Di Nardo, M.; Madonna, M.; Santillo, L.C. Safety management system: A system dynamics approach to manage risks in a process plant. *Int. Rev. Model. Simul. (IREMOS)* **2016**, *9*, 256. [CrossRef]
28. Banda, O.A.V.; Goerlandt, F.; Kuzmin, V.; Kujala, P.; Montewka, J. Risk management model of winter navigation operations. *Mar. Pollut. Bull.* **2016**, *108*, 242–262. [CrossRef]
29. Banda, O.A.V.; Goerlandt, F. ASTAMP-based approach for designing maritime safety management systems. *Saf. Sci.* **2018**, *109*, 109–129. [CrossRef]
30. Di Nardo, M.; Murino, T. The System Dynamicsin the Human Reliability Analysis Through Cognitive Reliability and Error Analysis Method: A Case Study of an LPG Company. *Int. Rev. Civ. Eng. (IRECE)* **2021**, *12*, 56. [CrossRef]
31. Almklov, P.G.; Rosness, R.; Storkersen, K.V. When safety science meets the practitioners: Does safety science contribute to marginalization of practical knowledge? *Saf. Sci.* **2014**, *67*, 25–36. [CrossRef]
32. Hollnagel, E. *Safety I and Safety II: The Pastand Future of Safety Management*; Ashgate: Aldershot, UK, 2014.
33. Hegde, S.; Wreathall, J.; Hettinger, A.Z.; Fairbanks, R.J.; Wears, R.L.; Bisantz, A.M. Towards the Development of a Resilience Engineering Tool to Improve Patient Safety: The RETIPS Approach. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*; SAGE Publications: Los Angeles, CA, USA, 2014; Volume 58, pp. 803–807.
34. Hegde, S.; Hettinger, A.Z.; Fairbanks, R.J.; Wreathall, J.; Krevat, S.A.; Jackson, C.D.; Bisantz, A.M. Qualitative findings from a pilot stage implementation of a novel organizational learning tool toward operationalizing the safety-II paradigm in health care. *Appl. Ergon.* **2020**, *82*, 102913. [CrossRef]
35. Sujan, M.A.; Huang, H.; Braithwaite, J. Learning from incidents in health care: Critique from a Safety-II perspective. *Saf.Sci.* **2017**, *99*, 115–121. [CrossRef]
36. Wang, F.; Tian, J.; Lin, Z. Empirical study of gap and correlation between philosophies Safety-I and Safety-II: A case of Beijing taxi service system. *Appl. Ergon.* **2020**, *82*, 102952. [CrossRef] [PubMed]
37. OECD. Guidelines for Resilience Systems Analysis: How to Analyse Risk and Build a Roadmap to Resilience. 2014. Available online: http://www.oecd.org/dac/Resilience%20Systems%20Analysis%20FINAL.pdf (accessed on 29 November 2020).
38. Ham, D.-H.; Park, J. Use of a big data analysis technique for extracting HRA data from event investigation reports based on the Safety-II concept. *Reliab. Eng. Syst. Saf.* **2020**, *194*, 106232. [CrossRef]
39. De Carvalho, P.V.R. The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience. *Reliab. Eng. Syst. Saf.* **2011**, *96*, 1482–1498. [CrossRef]
40. Thorvaldsen, T. The importance of common sense: How Norwegian coastal fishermen deal with occupational risk. *Mar. Policy* **2013**, *42*, 85–90. [CrossRef]
41. Wahl, A.; Kongsvik, T.; Antonsen, S. Balancing Safety I and Safety II: Learning to manage performance variability at sea using simulator-based training. *Reliab. Eng. Syst. Saf.* **2020**, *195*, 106698. [CrossRef]
42. Hollnagel, E.; Wears, R.; Braithwaite, J. From Safety-I to Safety-II: A White Paper. 2015. Available online: https://www.researchgate.net/publication/282441875 (accessed on 11 November 2020).
43. Hollnagel, E. A Tale of Two Safeties. *Nucl. Saf. Simul.* **2012**, *4*, 1–19.
44. Rasmussen, J.J. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Trans. Syst. Man Cybern.* **1983**, *SMC-13*, 257–266. [CrossRef]
45. Bracco, F.; Gianatti, R.; Pisano, L. Cognitive resilience in emergency room operations, a theoretical framework. In Proceedings of the Third Resilience Engineering Symposium, Antibes-Juan-les-Pins, France, 28–30 October 2008.
46. Coraddu, A.; Oneto, L.; de Maya, B.N.; Kurt, R. Determining the most influential human factors in maritime accidents: A data-driven approach. *Ocean Eng.* **2020**, *211*, 107588. [CrossRef]
47. Galieriková, A. The human factor and maritime safety. *Transp. Res. Procedia* **2019**, *40*, 1319–1326. [CrossRef]
48. March, J.G.; Olsen, J.P. The new institutionalism: Organizational factors in political life. *Am. Political Sci. Rev.* **1983**, *78*, 734–749. [CrossRef]
49. International Maritime Organization. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers. 2010. Available online: https://wwwcdn.imo.org/localresources/en/OurWork/HumanElement/Documents/34.pdf (accessed on 11 November 2020).
50. García-Herrero, S.; Mariscal, M.; García-Rodríguez, J.; Ritzel, D.O. Working conditions, psychological/physical symptoms and occupational accidents. Bayesian network models. *Saf. Sci.* **2012**, *50*, 1760–1774. [CrossRef]
51. Nævestad, T.-O.; Phillips, R.O.; Størkersen, K.V.; Laiou, A.; Yannis, G. Safety culture in maritime transport in Norway and Greece: Exploring national, sectorial and organizational influences on unsafe behaviours and work accidents. *Mar. Policy* **2019**, *99*, 1–13. [CrossRef]
52. Hu, Y.; Park, G. Collision risk assessment based on the vulnerability of marine accidents using fuzzy logic. *Int. J. Nav. Archit. Ocean Eng.* **2020**, *12*, 541–551. [CrossRef]
53. Lazakis, I.; Raptodimos, Y.; Varelas, T. Predicting ship machinery system condition through analytical reliability tools and artificial neural networks. *Ocean Eng.* **2018**, *152*, 404–415. [CrossRef]

54. Sarıalioğlu, S.; Uğurlu, Ö.; Aydın, M.; Vardar, B.; Wang, J. A hybrid model for human-factor analysis of engine-room fires on ships: HFACS-PV&FFTA. *Ocean Eng.* **2020**, *217*, 107992. [CrossRef]
55. Khadse, T.S.; Karmore, S.P. A Novel Approach for Fault Tolerance Control System and Embedded System Security. *Procedia Comput. Sci.* **2016**, *78*, 799–806. [CrossRef]
56. Zhao, Z.; Yang, Y.; Zhou, J.; Li, L.; Yang, Q. Adaptive fault-tolerant PI tracking control for ship propulsion system. *ISA Trans.* **2018**, *80*, 279–285. [CrossRef]
57. Islam, M.M.; Khondoker, M.H.; Rahman, C.M. Application of artificial intelligence techniques in automatic hull form generation. *Ocean Eng.* **2001**, *28*, 1531–1544. [CrossRef]
58. General Office of the State Council of the People's Republic of China. Maritime Traffic Safety Law of P.R.C. 2021. Available online: http://www.gov.cn/xinwen/2021-04/30/content_5604045.htm (accessed on 11 May 2021).
59. Yazdi, M.; Nikfar, F.; Nasrabadi, M. Failure probability analysis by employing fuzzy fault tree analysis. *Int. J. Syst. Assur. Eng. Manag.* **2017**, *8*, 1177–1193. [CrossRef]
60. Yazdi, M.; Daneshvar, S.; Setareh, H. An extension to fuzzy developed failure mode and effects analysis (FDFMEA) application for aircraft landing system. *Saf. Sci.* **2017**, *98*, 113–123. [CrossRef]
61. Weiss, D.J.; Dawis, R.V.; England, G.W. Manual for the Minnesota Satisfaction Questionnaire. In *Minnesota Studies in Vocational Rehabilitation*; Industrial Relations Center: Minneapolis, MN, USA, 1967.
62. Southwick, S.M.; Litz, B.T.; Charney, D. *Resilience and Mental Health. Challenges Across the Lifespan*; Cambridge University Press: London, UK, 2011.
63. Azadeh, A.; Salmanzadeh-Meydani, N.; Motevali-Haghighi, S. Performance optimization of an aluminum factory in economic crisis by integrated resilience engineering and mathematical programming. *Saf. Sci.* **2017**, *91*, 335–350. [CrossRef]
64. Ramzali, N.; Lavasani, M.R.M.; Ghodousi, J. Safety barriers analysis of offshore drilling system by employing fuzzy event tree analysis. *Saf. Sci.* **2015**, *78*, 49–59. [CrossRef]
65. Chang, D.-Y. Applications of the extent analysis method on fuzzy AHP. *Eur. J. Oper. Res.* **1996**, *95*, 649–655. [CrossRef]
66. Nguyen, S.; Chen, P.S.L.; Du, Y.; Shi, W. Aquantitativerisk analysis model with integrateddeliberativeDelphiplatformforcontainer-shippingoperationalrisks. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *129*, 203–227. [CrossRef]
67. Kaiser, H.F.; Rice, J.; Little, J.; Mark, I. Educational and Psychological Measurement. *Little Jiffy Mark IV* **1974**, *34*, 111–117.
68. Snedecor, G.W.; Cochran, W.G. *Statistical Methods*, 8th ed.; Iowa State University Press: Ames, IA, USA, 1989.
69. Cronbach, L.J. Coefficient alpha and the internal structure of tests. *Psychometrika* **1951**, *16*, 297–334. [CrossRef]
70. Hair, J.F., Jr.; Black, W.C.; Babin, B.J.; Anderson, R.E.; Tatham, R.L. *Multivariate Data Analysis*; Prentice Hall: Upper Saddle River, NJ, USA, 2006.
71. Di Nardo, M. Developinga Conceptual Framework ModelofIndustry4.0 for Industrial Management. *Ind. Eng. Manag. Syst.* **2020**, *19*, 551–560. [CrossRef]