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Identifying factors influencing total-loss marine accidents in the world: Analysis and evaluation based on ship types and sea regions

Identifying Factors Influencing Total-loss Marine Accidents in the World: Analysis and Evaluation Based on Ship Types and Sea Regions

Abstract

The world shipping industry is risky involving high uncertainties, and maritime safety has a direct bearing on human life, property and health of the marine environment. Therefore, safety has always been the focus of maritime transportation. Total-loss marine accidents present the most serious accident type in terms of economic cost. It is therefore crucial for decision-making and guidance on rational safety resource allocation through the analysis and evaluation of the influential factors of total-loss marine accidents. Its novelty lies in the pioneering analysis of all the factors solely influencing total-loss accidents in the whole world region, hence aid the development of a big database on total-loss marine accidents for rational safety policy making.

This paper involves 16 ship types and 13 main navigation sea regions and analyses the data on the total-loss marine accidents that occurred in the world from 1998 to 2018. As a result, 11 main influential factors are selected and evaluated by an improved entropy weight-TOPSIS model. The results show that, in the both models with respect to ship type and sea region, the main influential factors are foundering, stranding and fires/explosions. Based on such findings, this paper proposes a series of countermeasures with respect to different factors respectively, which will aid the relevant maritime safety authorities such as the International Maritime Organization and ship owners/operations to take effective risk control actions to avoid/reduce the occurrence of total-loss marine accidents in future.

Key words: Total-loss marine accident, entropy, TOPSIS, maritime safety, maritime risk

1. Introduction

Shipping is the lifeline of global economy, as about 90% of cargoes are transported by sea (Fink et al., 2002). Therefore, maritime safety has been the focus of the world shipping industry. However, sea transportation activities are often conducted in a complex and risky environment. More than 50,000 commercial vessels are engaged in international trade every day, so the busy sea transportation network has exposed ships to wrecks and hidden hazards (Chen et al., 2017). In addition, given that the world's hydro-logical conditions vary and sea transport traffic increases, particularly in narrow waters, navigational waters are becoming more complex and inconsistent, which increases the risk of navigation and could lead to more marine accidents. Total-loss marine accidents result in huge economic losses, and damage to the marine ecological environment. When oil tankers or ships carrying chemicals or dangerous goods are wrecked, the associated oil spills and large-scale discharge of pollutants have an incalculable impact on humankind and the ecological chain of the entire marine life.

Total-loss shipwrecks have become an important service target of the world's marine insurance industry, and have attracted much attention from coastal countries and maritime organizations (Liet al., 2009). Depending on the degree of cargo loss and the associated ship repair and maintenance cost, the total-loss shipwreck is further divided into the actual and constructive total loss. The actual total loss means that the ship or cargoes are completely lost, or have been so seriously damaged that they have lost their original forms and functions. The constructive total loss means that after a ship is in distress, the damage has not reached the degree of total loss, but the salvage expenses and repair costs, or one of them, will be higher than the value of the ship or cargoes after rescue, thus having no salvage value (Rose, 2013).

Historical data show that in the past decade, the number of annual total-loss marine accidents is decreasing, but casualties of these total-loss marine accidents remain high as far as specific ship types or sea regions are concerned. Many scholars have different approaches and perspectives on the factors influencing the accidents, but it is generally agreed that a total-loss marine accident is a comprehensive behavioral process affected by many factors, such as geographical factors and human manipulation during the navigation process (Arslan et al., 2016). In order to scientifically and effectively analyze the main causes of the world's total-loss marine accidents, this paper systematically investigates the influential factors against different ship types and sea regions based on the data from 1998-2018, using an improved entropy weight-TOPSIS method, aiming at aid decisions of safety authorities and ship owners and operators to actively respond to total-loss marine accidents, and reduce casualties and losses of ships and cargoes.

This paper is organized in six sections as follows. Following the definition and status quo description of total-loss marine accidents, this paper critically analyses and classifies the relevant literature and highlights the research gaps in Section 2. Section 3 analyzes the status quo of the world's total-loss marine accidents with respect to ship type and shipwreck locations, analyses the factors influencing the accidents. Section 4 describes the new improved model for the prioritization and selection of the factors in terms of their influential importance in this study. Section 5 uses the new model for the analysis of total-loss marine accidents and presents the results and new findings. The final section summarizes the conclusion of this paper and sets the future research directions.

2. Literature overview

Overall, global research on total-loss marine accidents is primarily conducted from a macroscopic perspective, focusing on the causes of accidents precipitated by specific ship types in particular geographical areas, and exploring improvement of maritime transportation safety from legal provisions and insurance liability. From the relevant literature, we review the main causes leading to the total-loss marine accidents in the world against ship type and sea region angles as follows.

A number of academic research findings reveal that the investigation and analysis of marine accidents are focusing on specific ships and risk responsibility assessments. Commercial fishing is one of the most unsafe ship types. Overturning is a decisive factor in the total loss of a shipwrecked commercial fishing vessel (Jin et al., 2001). Later, Jin (2014) collected the data on ship accidents from the U.S. Coast Guard from 2001 to 2008 and the result showed that the severity of fishing vessel damage was positively associated with destabilization, foundering, daytime wind speed, ship age and distance from the shore. In terms of oil tankers, oil spills seriously damage the marine economy development such as fishery and cause significant damages to marine ecological resources (Aguilera et al., 2010). Chen et al. (2018) established an entropy-weight grey-correlation analysis model to study oil tanker spill accidents in the world, disclosing that fires/explosions and collisions increase the risk of the accidents. Container ship is also one of the main ship types involving total loss accidents. Lu and Tsai (2008) looked at the impact of safe climate on container ship accidents, and used the logistic regression analysis to find that safety management practices, safety training and work safety dimensions have a significant impact on the crew mortality rate. Other scholars have also carried out studies of cargo ships (Akyildiz and Mentes, 2017), passenger ships (Yip et al., 2018), bulk carriers (Roberts et al., 2013), and ro-ro ships (Santos and Soares, 2009) in various ways in terms of the major factors contributing to economic losses, casualties, and environmental pollution in total-loss accidents.

In addition, scholars have conducted safety assessment and analysis of the total-loss marine accidents in different sea regions. Wang et al. (2014) used the fuzzy analytic hierarchy process to evaluate the safety of the South China Sea routes. The South China Sea routes are often threatened by natural and human factors, such as complex seabed terrain, extreme weather and piracy, and transportation in spring is found to have the highest risk. Rivai et al. (2012) discovered from the Japan Maritime Accident Investigation Administration (MAIA) that the proportion of ship collision accidents in Japan's surrounding routes accounted for 62.6% of all the marine accidents in 1998-2008. Erol and Başar (2015) analyzed 1,247 shipwrecks from 2001 to 2009 in the departure ports in the waters near the Black Sea (especially in the regions of Istanbul and Anaktu), and concluded that 60% of ship accidents were caused by human error. Goerlandt et al. (2017) conducted an analysis of the shipping accidents in the Northern Baltic region from 2007 to 2013 and made a practical training program for oil leaking accidents in winter conditions. Although the navigable waters in the Arctic waterways have expanded, the safety issue has constantly received a particular attention due to the complexity of maritime transportation in icy waters. Kum and Sahin (2015) investigated the causes of marine accidents to reduce the potential threat of human negligence in the Arctic waterways in the future.

In response to the global marine accident investigation, scholars have used various mathematical methods to study the main influential factors and assess their risk contributions. Specifically, the Human Factors Analysis and Classification System (HFACS) has a wide application. Uğurlu et al. (2018) proposed a human factor analysis and classification system for passenger ship accidents (HFACS-PV), which allowed the cause of accidents to be conceptualized as an interaction between active and potential system failures. Chauvin et al. (2013) used HFACS to determine the contributing factors in ship collisions, and jointly used the MCA and hierarchical clustering methods to analyze the human factors and organizational factors in the ship collisions reported by the Maritime Accident and Investigation Board (MAIB) and the Transportation Safety Board (TSB). These methods calculate the priority weight of the causes of accidents related to human errors. Akyuz and Celik (2014) combined HFACS with a Cognitive Mapping (CM) method, which provides a distribution of human errors by considering ship operation evidence and helps identify and prevent human errors in marine accidents. Apart from the human oriented accident analysis, different mathematical methods have been applied in the studies on shipwrecks, including Bayesian Belief Networks (e.g. Zhang et al., 2016), Markov Chain Monte Carlo (MCMC) (e.g. Faghih et al., 2014), and fuzzy extended fault tree analysis (FFTA) (e.g. Celiket et al., 2010). Along with the new models and methods, the accident data come from different sources such as MAIB and TSB. For example, Mullai and Paulsson (2011) designed a conceptual model for marine accident analysis based on the Swedish Maritime Administration database to determine the main factors of accidents.

In addition, total-loss accidents were also analyzed with a focus on sea damage from the perspectives of maritime legal provisions and insurance liability (Merkinet al., 2014; Li and Wonham, 1999; Knapp and Heij, 2017). However, to the authors' best knowledge, research on the comprehensive analysis of the influencing factors of total-loss marine accidents against various ship types and sea regions are still scanty. Meanwhile, previous studies has dealt with these two criteria by means of subjective assessment. In this paper, we adopts an improved entropy weight method to systematically analyze the objective weighting of ship types and sea regions in total-loss accidents, and applies a TOPSIS model to rank the main factors influencing the total-loss marine accidents in the world.

3. Selection and data sources of the factors influencing total-loss marine accidents

3.1. Analysis and selection of the major factors relating to total-loss marine accidents

The influential factors of total-loss marine accidents in the world are complex and diversified. Human error is the main cause contributing to 60%-90% of the marine accidents of ships (Baker and McCafferty, 2005). However, each total-loss marine accident has different degrees of damage due to differences in seaworthiness, cargo type and geographical environment. To make the analysis results accurate and effective, this paper refers to the Lloyd's List Intelligence Casualty Statistics database, and selects the following 11 factors based on their occurrence frequency. Their definitions and descriptions are shown in Table 1.

Table 1

Main Influential Factors of Total-loss Marine Accidents in the World

Series No.	Factors (Abbreviation)	Descriptions
F_1	Collision (CS)	A ship comes into inevitable contact with other ships in voyage waters, anchorage areas or mooring areas, which often causes damage to ships (Chae and Yoshida, 2010). It is the most common, most professional, and most difficult type among all maritime infringement disputes.
F_2	Contact (CT)	A ship comes into inevitable contact with fixed facilities or obstacles (such as port facilities, buoys, and fishing nets), which causes damage to ships.
F_3	Fire/Explosion (FE)	A fires or explosion caused by ships for various reasons (improper cargo stowage in the cabin or unseaworthiness of the ship, etc.), but the fires indirectly caused by ship collisions or stranding etc. are excluded (Baalisampang et al., 2018).
F_4	Foundered (FD)	A ship is flooded or loses buoyancy due to overload, stowage or improper loading, improper operation, water leakage from the hull, or other unknown factors, causing the deck of the cargo hold or barge, the highest deck of the motor ship to be submerged by at least one half (Hassel et al., 2011).
F_5	Hull damage (HD)	A ship hull is damaged due to various reasons. Damage to the hull may occur during the voyage or during port operations.
F_6	Machinery damage/failure (MD)	An equipment engine of the ship fails, preventing the ship from operating normally.
F_7	Missing/overdue (MO)	A ship is lost during navigation and fails to arrive at its destination from the location of its last acknowledgement within a reasonable period of time, and stay unreachable after a considerable period of time. It is considered as a total loss.
F_8	Piracy (PI)	During the voyage, a ship encounters illegal forcible boarding (or attempts to board) and is subjected to violence or other threats, and the ship, people or property on board is detained or pillaged.

F_9	War loss/damage (WD)	Due to war, hostilities or armed conflicts, or after the end of a war, bombs and submarine mines are left in some sea regions and have not been detonated after such areas are scanned. A ship triggers such a bomb and explodes when traversing such areas.
F_{10}	Wrecked/stranded (WS)	When a ship reaches an area with a shallow water level, it touches the bottom of the water, the shallow riverbed or the beach, and thus loses its buoyancy and cannot sail normally. (Youssef et al., 2018) The ship crews' competence, attitude toward safety work and the properness of the measures they take to refloat the stranded ship all affect the severity of a marine accident.
F_{11}	Miscellaneous (MI)	Other factors include external force majeure such as weather conditions, and circumstances that cannot be defined as the cause of the accident.

Source: Lloyd’s List Intelligence Casualty Statistics

3.2. Analysis of current situation of total-loss marine accidents

The data supporting this study is collected from Lloyd's List Intelligence Casualty Statistics covering the period of January 1998 to July 2018.

From January 1998 to July 2018, a total of 3,976 total-loss marine accidents occurred in the world. The annual distribution of such accidents indicates that the world's total-loss marine accidents are steadily decreasing, as shown in Fig.1.

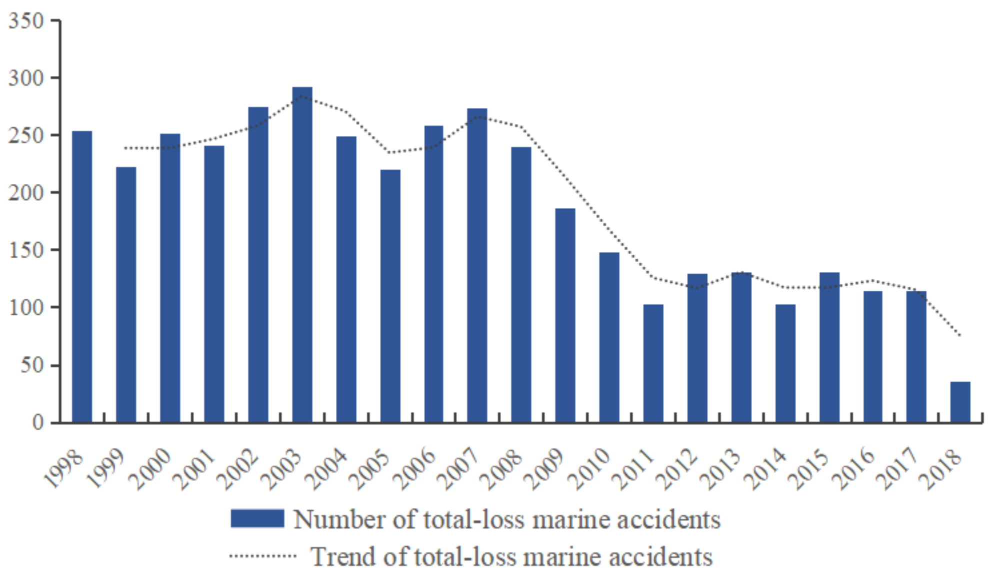

Fig.1. Total-loss Marine Accidents from January 1998 to July 2018 in the World

The total-loss marine accidents significantly fell lately (e.g. 2016 – 2018), dropping to a level of 46% of the number in 2003. However, the factors causing marine accidents of various ship types and in different sea regions varied. In terms of ship types, general cargo ships and fishing vessels have a high record in combination, accounting for 60% of the total accidents, as shown in Fig.2. Specifically, statistics show that foundering is the main reason for total-loss marine accidents among general cargo ships and fishing vessels, accounting for 43% and 57% respectively. In addition to human errors, bad weather is also a factor that causes ships to sink.

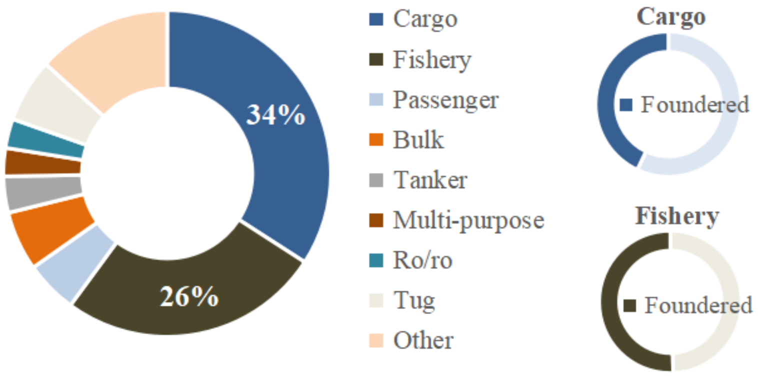

Fig.2. Total-loss Marine Accidents of Major Ship Types from January 1998 to July 2018

Moreover, with the shipping demand and waterway traffic density increasing, the shipping environment is becoming more complex. It is worth of investigating the main factors that cause total-loss marine accidents in different sea regions, adding to the complexity the geopolitical stability, complexity of regional waters and the differences in laws and policies from different countries. According to the 20-year statistics, 18.7% of the world's total-loss marine accidents occurred in South China, Indo-China Peninsula, Indonesia and the Philippines, 10.8% of such accidents occurred in Japan, South Korea and the Northern China waters. The probability of total-loss marine accidents was also high in the waters near the Eastern Mediterranean and the Black Sea, accounting for 10.4%, as shown in Fig.3. Compared with ocean transportation, most of the ships in these locations are for offshore transportation, carrying a small tonnage and presenting poor handling emergencies (Wang and Yang, 2018). In addition, the accident locations cover three or more countries are grey zones where the shipwreck rescue responsibility cannot be effectively determined. Therefore, the probability and severity of shipwrecks such regions are generally higher.

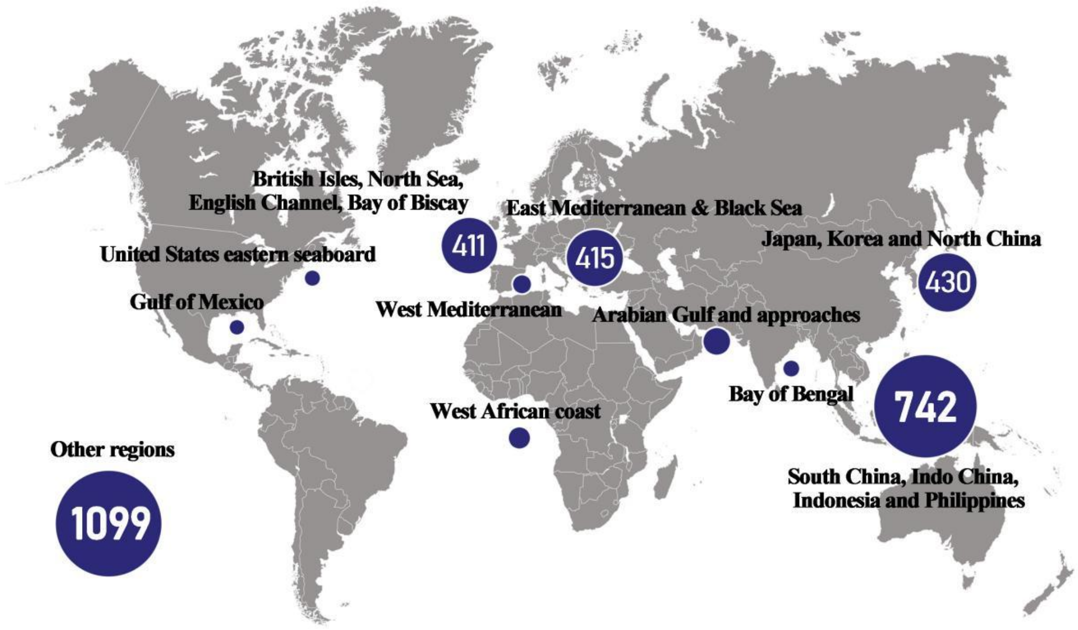

Fig.3. Total-loss marine accidents that occurred in major sea regions from January 1998 to July 2018

4. Model building

4.1. Basic framework of model

The entropy weight method has been widely used in such fields as social economy. The basic principle is to determine the objective weight based on the magnitude of the indicator variability (Huang et al., 2018). Meanwhile, the TOPSIS multi-criteria evaluation model ranks the limited number of existing objects in terms of their relative advantages and disadvantages based on their closeness to the ideal objectives (Mavi et al., 2016). The organic combination of the two can be used for systematic assessment and risk and safety assessment in the field of traffic engineering (Yang et al., 2009; Li et al., 2011).

This paper uses an entropy weight-TOPSIS method to identify the influential factors of the global total-loss marine accidents, and judge whether they are the main indicators. The entropy weight method determines the weights of various ship types and sea regions against which the influential factors of total-loss marine accidents are evaluated to effectively overcome the subjectivity of data in weighting. The flowchart of the model is shown in Fig.4.

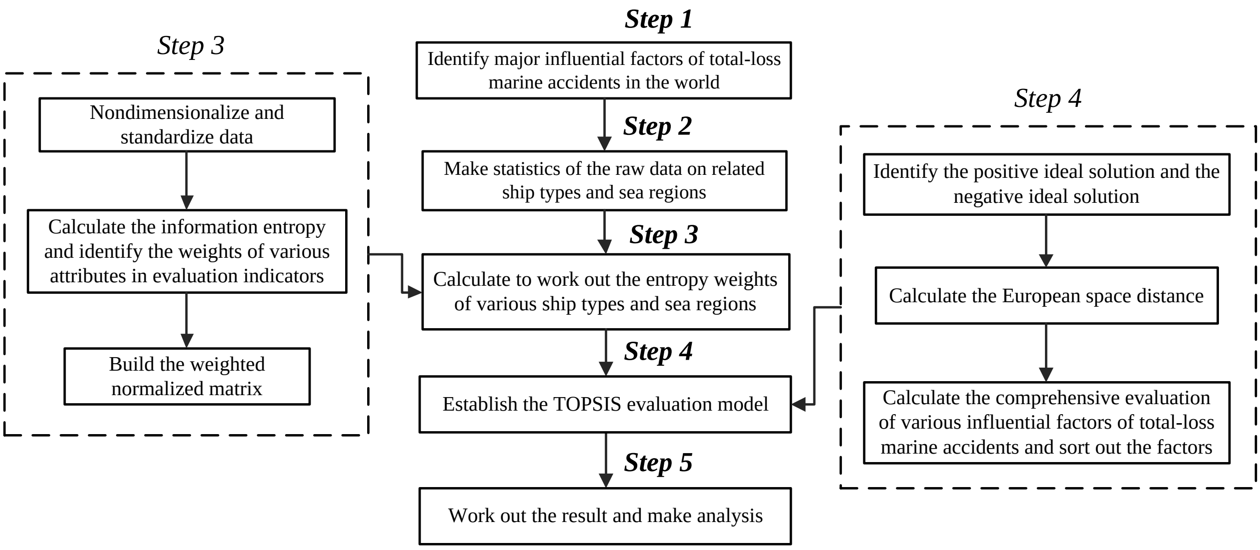

Fig.4. The Entropy weight-TOPSIS model framework about influential factors of the world's total-loss marine accidents

4.2. Steps for the model development

4.2.1. An improved entropy weight method to determine the attributive weights of different ship types and sea regions

Step 1: Get the evaluation indicator matrix based on the raw data:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where x_{ij} is the score of the i-th attribute (e.g. ship type or sea region) against the j-th influential factor(Table 1). m represents the number of the attributes in ship types or sea regions. n is equal to 11 meaning the total amount of the influential factors in Table 1.

Step 2: In the comprehensive evaluation indicator system, the data is nondimensionalized due to differences between factors and dimensions among the attributes. The extreme value processing method is a general method for processing data. However, it has errors in processing the data in this paper. Therefore, the standardized translation entropy method is used for the improvement of data processing:

$$x_{ij}^{*} = \frac{x_{ij} - \overline{x_j}}{s_j}, \quad i = 1,2,\ldots,m; \quad j = 1,2,\ldots,n \tag{2}$$

Where $\overline{x_i} = \frac{1}{\mathrm{n}}\sum_{i=1}^{\mathrm{n}} x_{ij}$ and $s_i = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{ij} - \overline{x_i})^2}$, $i = 1,2,\ldots,m$ are the sample mean and sample standard deviation of the ith attribute.

There is a negative value for the dimensionless data x_{ij}^{*} after standardization. However, the entropy weight method requires $x_{ij} > 0$, so it is necessary to translate x_{ij}^{*} to get new data: $R_{ij} = x_{ij}^{*} + A$, where A is the amplitude of the translation, and the value should be as close to $\min(x_{ij}^{*})$ as possible to achieve $R_{ij} > 0$.

Step 3: Standardize each data in the target space. This paper uses an averaging method. The result after the standardization is:

$$p_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}, \quad i = 1,2,\ldots,m; \quad j = 1,2,\ldots,n \tag{3}$$

Where P_{ij} stands for the contribution of the i-th attribute against the j-th influential factor.

Step 4: Calculate the information entropy. Based on the definition of relevant information entropy in the information theory, we determine the information entropy of the i-th attribute (e.g. ship type or sea region) by all the influential factors listed in Table 1:

$$E_i = -\frac{1}{\ln n}\sum_{j=1}^{n} p_{ij} \ln p_{ij}, \quad i = 1,2,\ldots,m \tag{4}$$

If $p_{ij} = 0$, define $\lim_{\mathrm{p_{ij}} \to 0} p_{ij} \ln p_{ij} = 0$ to get the information entropy of each attribute E_1, E_2, …, E_m.

Step 5: Determine the weighting of each ship type and sea region in terms of its influence to total-loss marine accidents. Calculate the entropy weight of each attribute based on the determined information entropy:

$$W_i = \frac{1 - E_i}{\sum_{i=1}^{m} 1 - E_i} \tag{5}$$

Where $1-E_i$ is the deviation factor. It indicates the importance of the attribute in the target space. The larger the value, the greater the contribution of the attribute to the total-loss shipwrecks.

Step 6: Assign weights to the matrix P_{ij} to form a weighted normalization matrix. The matrix is represented by H:

$$H=(H_{ij})_{m\times n}=w_i\times p_{ij}=\begin{bmatrix} w_1p_{11} & w_1p_{12} & \cdots & w_1p_{1n} \\ w_2p_{21} & w_2p_{22} & \cdots & w_2p_{2n} \\ \vdots & \vdots & & \vdots \\ w_mp_{m1} & w_mp_{m1} & \cdots & w_mp_{mn} \end{bmatrix},\quad i=1,2,\ldots,m;\ j=1,2,\ldots,n \tag{6}$$

4.2.2. TOPSIS evaluation model

According to the TOPSIS theory, the positive ideal solution of the influential factors is the optimal set of data in which each attribute value has reached the maximum value of all the influencing factors, because the evaluation is to find the most influencing factors in terms of their risk contributions (the higher the value, the more influential the factor on total loss). The negative ideal solution is the opposite. With respect to each attribute, it is necessary to find a set of the most influential factors that are the closest to the positive and the farthest from the negative ideal solutions. We can then evaluate the correlation between the influential factors of the total-loss shipwrecks and the defined attributes (ship type and sea region).

Step 7: Determine the positive ideal solution V^+ and the negative ideal solution V^-, where:

Positive ideal solution: $V^+=[(\max\ \mathrm{h}_{\mathrm{ij}}^*/i\in I_1)]=[v_1^+,v_2^+,\ldots\ldots,v_m^+]$ (7)

Negative ideal solution: $V^-=[(\min\ \mathrm{h}_{\mathrm{ij}}^*/i\in I_1)]=[v_1^-,v_2^-,\ldots\ldots,v_m^-]$ (8)

Based on the results from this step, we can figure out the importance of each influential factor against each ship type and/or sea region.

Step 8: Calculate the distances between the indicator values of the influential factors from the positive ideal solution and from the negative ideal solution respectively:

$$D_{\mathrm{j}}^{+} = \sqrt{\sum_{i=1}^{m} (h_{ij} - v_i^{+})^2}\,,\ j = 1,2,\ldots,n \tag{9}$$

$$D_{\mathrm{j}}^{-} = \sqrt{\sum_{i=1}^{m} (h_{ij} - v_i^{-})^2}\,,\ j = 1,2,\ldots,n \tag{10}$$

Step 9: Finally, calculate the relative closeness of the influential factor unit of total-loss shipwrecks to the positive ideal solution and to the negative ideal solution (namely the comprehensive assessment index) C_j:

$$C_{\mathrm{j}} = \frac{D_j^{-}}{(D_j^{-} + D_j^{+})},\quad j = 1,2,\ldots,n \tag{11}$$

The comprehensive assessment coefficient C_j represents the degree of relevance between the reference attribute sequence and the influential factors of the total-loss shipwrecks. The larger the value of C_j, the greater the correlation between the j-th influential factor and the corresponding attribute. The closeness C_j ranges from 0 to 1, and the one with the highest closeness C_j has the highest influence. Finally, we can with respect to C_j prioritize the influential factors of total-loss marine accidents.

5. Examples of identification of total-loss marine accident types in the world

5.1. Contribution of influential factors to total-loss marine accidents in the world

This paper collects data on the world's total-loss marine accidents from January 1998 to July 2018 and applies the proposed model in Section 4 to analyse the importance of each influential factor against ship type and sea region. The symbols for the 11 main influential factors of the total-loss marine accidents are defined in Table 1. Meanwhile, the symbols of the ship type and sea region attributes are T_1 to T_{16} and R_1 to R_{13} respectively (see Table 2).

Table 2
Serial Numbers of Ship Type and Sea Region Attributes

Series No.	Type of ship	Series No.	Sea region
T_1	Cargo	R_1	Arabian Gulf and approaches

T_2	Fishery	R_2	Bay of Bengal
T_3	Passenger	R_3	British Isles, North Sea, English Channel, Bay of Biscay
T_4	Bulk		
T_5	Tanker	R_4	East Mediterranean & Black Sea
T_6	Chemical	R_5	Gulf of Mexico
T_7	LPG	R_6	Japan, Korea and North China
T_8	Container	R_7	South Atlantic and East Coast South America
T_9	Multi-purpose		
T_{10}	Ro/ro	R_8	South China, Indo China, Indonesia and Philippines
T_{11}	Reefer		
T_{12}	Tug	R_9	United States eastern seaboard
T_{13}	Supply/offshore	R_{10}	West African Coast
T_{14}	Barge	R_{11}	West Indies
T_{15}	Dredger	R_{12}	West Mediterranean
T_{16}	Other	R_{13}	Other Regions

5.1.1. Analysis of influential factors of total-loss marine accidents based on ship type

The raw data are obtained by configuring the data in the Lloyd's List Intelligence Casualty Statistics database that are relevant to the ship type and influential factors of total-loss shipwrecks. On this basis, we used the improved entropy weight method to calculate the weight of each ship type to the total-loss marine accidents. According to Formula (1), we established the evaluation indicator matrix X_T, and Formula (2) is used to nondimensionalize the data to obtain the dimensionless evaluation indicator matrix R_T (see Table 3).

Table 3
Dimensionless Data on Total-loss Marine Accidents in the World Based on Ship Type

R_T	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
T_1	1.1084	0.2391	0.6099	3.7043	0.8652	0.7254	0.2026	0.1965	0.1661	1.7832	0.4093
T_2	0.9392	0.3178	1.4582	3.8345	0.7138	0.4748	0.2905	0.2700	0.2700	1.1031	0.3383
T_3	0.6979	0.2904	2.3276	3.4387	0.6979	0.4386	0.2164	0.2164	0.2164	1.1794	0.2904
T_4	1.1007	0.0920	0.6972	2.8762	1.0200	0.8183	0.0516	0.0516	0.0516	2.8762	0.3744
T_5	0.7118	0.0511	2.0992	3.4206	0.5797	0.7118	0.0511	0.1832	0.1172	1.5046	0.5797
T_6	0.8364	0.2292	3.2651	2.2531	1.0388	0.6340	0.0268	0.0268	0.0268	1.4436	0.2292
T_7	0.7860	0.1038	2.1503	2.8325	0.1038	1.4682	0.1038	0.1038	0.1038	2.1503	0.1038

T_8	1.2985	0.0967	0.8979	3.1679	0.4973	1.2985	0.0967	0.0967	0.0967	2.3667	0.0967
T_9	0.4015	0.2581	2.6963	3.1266	0.8318	0.6166	0.1863	0.1863	0.1863	1.2620	0.2581
T_{10}	0.7837	0.1758	1.7389	3.3020	0.6100	1.0442	0.0890	0.0021	0.0021	1.9994	0.2627
T_{11}	0.5966	0.0523	1.3223	2.5923	0.2338	1.5038	0.2338	0.0523	0.0523	2.9552	0.4152
T_{12}	0.7026	0.5746	0.6813	4.0504	0.6599	0.5960	0.4467	0.4467	0.4254	0.8305	0.5960
T_{13}	1.0593	0.3831	1.5423	3.7642	0.3831	0.3831	0.2865	0.2865	0.1899	1.2525	0.4797
T_{14}	0.7971	0.5486	0.6729	3.9025	0.5486	0.4244	0.3623	0.3623	0.3623	1.5424	0.4865
T_{15}	1.1679	0.4325	0.6426	4.0043	0.6426	0.5375	0.4325	0.4325	0.4325	0.7476	0.5375
T_{16}	1.4387	0.3949	1.2150	3.7499	1.0659	0.5440	0.1712	0.0967	0.0967	0.8422	0.3949

Using Formula (3), we standardized each piece of data in the target space to obtain a standardized matrix P_T. The calculation results are shown in Table 4. Therefore, the entropy value E_{Ti} and entropy weight W_{Ti} of the impact of the ship type attribute on the total-loss marine accidents are calculated by Formula (4) and (5) (see Table 5).

Table 4

Standardized Calculation Results of Data on Total-loss Marine Accidents in the World Based on Ship Type

P_T	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
T_1	0.1107	0.0239	0.0609	0.3701	0.0864	0.0725	0.0202	0.0196	0.0166	0.1781	0.0409
T_2	0.0938	0.0317	0.1457	0.3831	0.0713	0.0474	0.0290	0.0270	0.0270	0.1102	0.0338
T_3	0.0697	0.0290	0.2325	0.3435	0.0697	0.0438	0.0216	0.0216	0.0216	0.1178	0.0290
T_4	0.1100	0.0092	0.0697	0.2873	0.1019	0.0817	0.0052	0.0052	0.0052	0.2873	0.0374
T_5	0.0711	0.0051	0.2097	0.3417	0.0579	0.0711	0.0051	0.0183	0.0117	0.1503	0.0579
T_6	0.0836	0.0229	0.3262	0.2251	0.1038	0.0633	0.0027	0.0027	0.0027	0.1442	0.0229
T_7	0.0785	0.0104	0.2148	0.2830	0.0104	0.1467	0.0104	0.0104	0.0104	0.2148	0.0104
T_8	0.1297	0.0097	0.0897	0.3165	0.0497	0.1297	0.0097	0.0097	0.0097	0.2364	0.0097
T_9	0.0401	0.0258	0.2694	0.3123	0.0831	0.0616	0.0186	0.0186	0.0186	0.1261	0.0258
T_{10}	0.0783	0.0176	0.1737	0.3299	0.0609	0.1043	0.0089	0.0002	0.0002	0.1997	0.0262
T_{11}	0.0596	0.0052	0.1321	0.2590	0.0234	0.1502	0.0234	0.0052	0.0052	0.2952	0.0415
T_{12}	0.0702	0.0574	0.0681	0.4046	0.0659	0.0595	0.0446	0.0446	0.0425	0.0830	0.0595
T_{13}	0.1058	0.0383	0.1541	0.3760	0.0383	0.0383	0.0286	0.0286	0.0190	0.1251	0.0479
T_{14}	0.0796	0.0548	0.0672	0.3899	0.0548	0.0424	0.0362	0.0362	0.0362	0.1541	0.0486
T_{15}	0.1167	0.0432	0.0642	0.4000	0.0642	0.0537	0.0432	0.0432	0.0432	0.0747	0.0537
T_{16}	0.1437	0.0394	0.1214	0.3746	0.1065	0.0543	0.0171	0.0097	0.0097	0.0841	0.0394

From Table 4, we will be able to clearly know the most and least influential factor

against each of different ship types in terms of total-loss marine accidents.

Table 5

Entropy Value and Entropy Weight of Each Ship Type Attribute

	E_{Ti}	W_{Ti}
T_1	0.8070	0.0581
T_2	0.8206	0.0540
T_3	0.8010	0.0599
T_4	0.7632	0.0713
T_5	0.7775	0.0669
T_6	0.7583	0.0727
T_7	0.7438	0.0771
T_8	0.7608	0.0720
T_9	0.7908	0.0629
T_{10}	0.7546	0.0738
T_{11}	0.7591	0.0725
T_{12}	0.8478	0.0458
T_{13}	0.8143	0.0559
T_{14}	0.8333	0.0502
T_{15}	0.8426	0.0473
T_{16}	0.8015	0.0597

Using Formula (6), we assign the weight to each ship type back to the evaluation matrix (i.e. Table 3) to establish the TOPSIS model and analyse the main influential factors of total-loss marine accidents in the world. We used Formula (7) and (8) to determine the positive V_T^+ and negative V_T^- ideal solutions for each evaluation attribute (see Table 6), while using Formula (9) and (10), we calculated the distances between the indicator value of each influential factor from the positive and negative ideal solutions D_T^+ and D_T^- respectively. Finally, we calculated the relative closeness C_T of the influential factors to the optimal evaluation target using Formula (11). The results are shown in Table 7.

Table 6

Optimal Solution and Worst Solution for Influential Factors of Total-loss Marine Accidents (ship type)

	V_T^+	V_T^-
T_1	0.0215	0.0010
T_2	0.0207	0.0015

T_3	0.0206	0.0013
T_4	0.0205	0.0004
T_5	0.0229	0.0003
T_6	0.0237	0.0002
T_7	0.0218	0.0008
T_8	0.0228	0.0007
T_9	0.0197	0.0012
T_{10}	0.0244	0.0000
T_{11}	0.0214	0.0004
T_{12}	0.0185	0.0019
T_{13}	0.0210	0.0011
T_{14}	0.0196	0.0018
T_{15}	0.0189	0.0020
T_{16}	0.0224	0.0006

Table 7

European Space Distance D_T^+ and D_T^- Based on Ship Type and Comprehensive Evaluation Result C_T

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
D_T^+	0.0040	0.0063	0.0026	0.0001	0.0048	0.0043	0.0065	0.0066	0.0067	0.0022	0.0059
D_T^-	0.0004	0.0000	0.0019	0.0063	0.0002	0.0005	0.0000	0.0000	0.0000	0.0021	0.0000
C_T	0.0956	0.0016	0.4203	0.9904	0.0454	0.0948	0.0004	0.0002	0.0000	0.4786	0.0068

5.1.2. Analysis of influential factors of total-loss marine accidents based on sea region

Table 8

Standardized Calculation Results of Data on Total-loss Marine Accidents in the World Based on Sea Region

P_R	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
R_1	0.0580	0.0365	0.1140	0.3980	0.1011	0.0537	0.0107	0.0150	0.0107	0.1441	0.0580
R_2	0.1336	0.0212	0.0675	0.3980	0.1071	0.0807	0.0146	0.0212	0.0278	0.1137	0.0146
R_3	0.0984	0.0240	0.1191	0.4004	0.1046	0.0509	0.0157	0.0136	0.0136	0.1129	0.0467
R_4	0.0485	0.0100	0.1096	0.3427	0.0666	0.1028	0.0100	0.0055	0.0055	0.2545	0.0440
R_5	0.0812	0.0586	0.1263	0.4143	0.0642	0.0473	0.0303	0.0303	0.0303	0.0699	0.0473
R_6	0.2244	0.0239	0.0592	0.3618	0.0480	0.0480	0.0221	0.0183	0.0183	0.1483	0.0276
R_7	0.0637	0.0298	0.1724	0.3966	0.0502	0.0705	0.0230	0.0230	0.0230	0.1045	0.0434
R_8	0.1198	0.0257	0.1016	0.4052	0.0641	0.0611	0.0257	0.0257	0.0226	0.1168	0.0318
R_9	0.0773	0.0275	0.1645	0.3949	0.1085	0.0462	0.0213	0.0213	0.0213	0.0898	0.0275

R_{10}	0.0582	0.0250	0.1689	0.3791	0.1025	0.0693	0.0084	0.0195	0.0084	0.1467	0.0139
R_{11}	0.0532	0.0240	0.0896	0.3883	0.0896	0.0604	0.0240	0.0167	0.0167	0.1916	0.0459
R_{12}	0.0915	0.0147	0.1754	0.3431	0.0706	0.0636	0.0007	0.0007	0.0007	0.2173	0.0217
R_{13}	0.0527	0.0255	0.1399	0.3856	0.0705	0.0546	0.0218	0.0190	0.0162	0.1784	0.0358

Table 9

European Space Distance D_R^+ and D_R^- Based on Sea Region and Comprehensive Evaluation Result C_R

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
D_R^+	0.0068	0.0099	0.0052	0.0000	0.0071	0.0079	0.0104	0.0104	0.0104	0.0044	0.0094
D_R^-	0.0006	0.0000	0.0011	0.0105	0.0004	0.0002	0.0000	0.0000	0.0000	0.0018	0.0000
C_R	0.0812	0.0013	0.1740	1.0000	0.0516	0.0278	0.0001	0.0001	0.0001	0.2885	0.0049

Finally, we combined the results from Tables 7 and 9 (against ship type and sea region respectively) and takes the average value to obtain the influential factors of total-loss marine accidents in the world, and rank them in Table 10).

Table 10

Influential Factors of Total-loss Marine Accidents in the World and Ranking

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}
R_j	0.0884	0.0015	0.2972	0.9952	0.0485	0.0613	0.0003	0.0002	0.0001	0.3836	0.0059
Ranking	4	8	3	1	6	5	9	10	11	2	7

Note: For R_j, $j = 1,2,\ldots,11$

5.2. Analysis of influential factors of total-loss marine accidents in the world

We developed an improved entropy weight-TOPSIS model, and comprehensively identified and prioritize the influential factors of the world's total-loss marine accidents based on the ship type and sea region attributes in Fig.4.

As far as ship type is concerned, the LPG (0.0771), Ro/Ro (0.0738) and Chemical tankers (0.0727) attributes carry the highest weights. As trade demand goes up, cargoes are also diversifying, which increases the accident risk for ships transporting special cargoes.

The observation of the sea region attributes shows that the West Mediterranean (0.0970), East Mediterranean & Black Sea (0.0880) and West African coast (0.0826) sea regions have the greatest impact on the total-loss marine accidents. Due to the expansion of the Suez Canal in the Mediterranean Sea, a large number of commercial vessels have chosen to go through it (Zodiatis et al., 2016), which has increased the probability of total-loss marine accidents.

Fig.4. Contribution of Different Ship Types and Sea Regions to Total-loss Marine Accidents

The overall assessment results show that major influential factors of accidents are consistent, regardless of the ship type or sea region. The findings aid the division of accident factors into three categories: major accident factors (Founder, Wrecked/stranded, Fire/Explosion), minor accident factors (Collision, Machinery damage/failure, Hull damage), and weak accident factors (Miscellaneous, Contact, Missing/overdue, Piracy, War loss/damage), as shown in Fig.5.

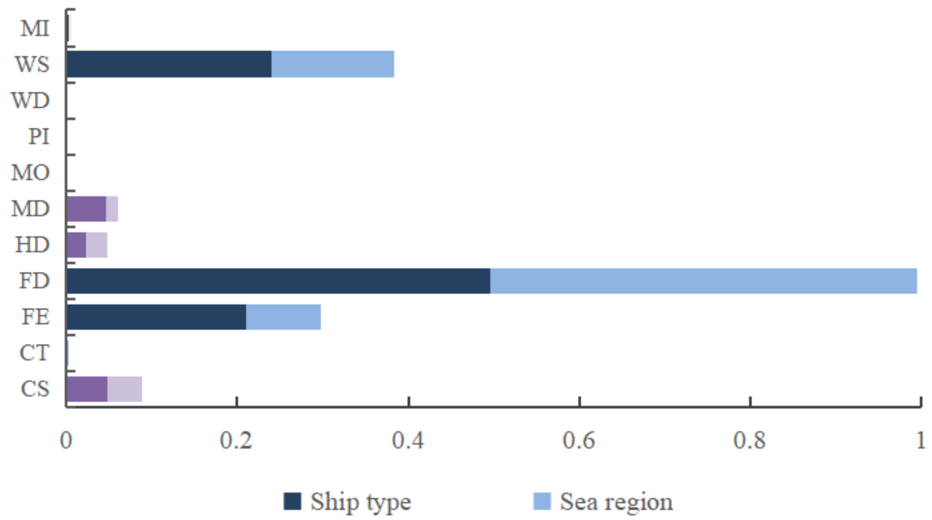

Fig.5. Influential factors of total-loss marine accidents in the world

Foundered, Wrecked/stranded and Fire/Explosion are the three major influential factors of the total-loss marine accidents in the world, and the governments and the International Maritime Organization need to attach importance to these three factors and take effective measures. The specific reasons are as follows.

- **Foundered**

Foundering, once occurring, often leads to a catastrophic result such as the total loss of the ship and cargoes and the death and disappearance of some or all of the crew (Jin et al., 2001). The main reason of foundering is that in the case of heavy weather, a large number of waves on the deck cause seawater to pour into the cargo hold and the engine room, causing the cargoes to move and generate a free surface impact, resulting in insufficient dynamic stability of the ship. Eventually the hull is broken or flooded and loses buoyancy (Lee et al., 2017). To prevent foundering, a ship should get relevant weather information in a timely manner, and take effective safety measures before sailing. Meanwhile, ship companies should strengthen ship safety inspection to ensure that their ships are seaworthy, and use wireless technologies to conduct real-time monitoring over the ships' integrity at sea.

- **Wrecked/stranded**

Ship stranding is a result of superposition of various conditions. The ocean topography is complex and dynamic, and ships inevitably suffer from many sudden changes and uncontrollable factors, such as narrow channels and big changes in tides (Nguyen et al., 2011). However, stranding is often associate with the crew's maneuvering faults (Youssef et al., 2018). Therefore, when a ship is sailing in a complex waterway, the crew should pay attention to the unfavorable factors with caution. Before the ship arrives at a port, the crew should also get information on the port, fully assess the navigational risks, and set a safety plan on port entry and exit.

- **Fire/Explosion**

Fires and explosions are the most serious causes of casualties, and human errors, thermal reactions, electrical faults and unknown factors can all cause fires or explosions (Baalisampang et al., 2018). Human errors are the most common factor. Other factors such as poor goods package, insufficient risk identification and incorrect loading that could lead to shipping accidents (Uğurlu, 2016). To prevent the total-loss marine accidents caused by fires/explosions, it is necessary for marine practitioners, including manufacturers and relevant stakeholders in the transportation chain, to be responsible for safe transportation of cargoes and to receive systematic training on safety and fire drills.

6. Conclusion and prospect

In the maritime industry, it is of utmost importance to ensure the safety of the crew and prevent ship damage and loss of goods. This paper studies the influential factors of the total-loss marine accidents in the world, and provides a scientific guide for ship safety management. Its main contributions are threefold. First, this paper makes a comprehensive description of the basic situations of total loss accidents from the perspectives of ship type and sea region, and looks at their contribution to the total-loss marine accidents in the world. Second, this paper provides a feasible mathematical model for the analysis of the influential factors of total-loss marine accidents in the world. Third, relevant research findings help maritime safety authorities and practitioners to safeguard total loss risks total-loss marine accident prevention.

This paper collects the data in 1998 -2018 from Lloyd’s List Intelligence Casualty Statistics, extracts 16 ship types, 13 sea regions and 11 major accident factors, and builds an improved entropy weight-TOPSIS model. In the end, the analysis of the ship type model and sea region model shows that foundering, stranding and fire/explosion are the most important influential factors of accidents. Maritime authorities need to strengthen safety training for maritime practitioners to increase their sense of operation and sense of responsibility. Collisions, machine breakdown/faults and hull damage are secondary influential factors, and shipbuilding technicians should develop ships with crashworthy structures and improve the performance of a ship in all aspects. Such factors as contact, piracy, missing and war have a great impact on specific ship types or in specific sea regions, but the statistics shows that their impact on total loss are relatively weak.

In terms of the limitation of this paper, and the following two aspects can be further investigated in the future. First, more extensive and adequate contributing factors for total-loss marine accidents can be taken into account. In addition to ship types and sea regions, information on ports, ship routes and ship registry can be included into the investigation. Second, the influential factors of total-loss marine accidents should be further broken down, and the human factors behind an accident should be specified. Meanwhile, with the application of emerging techniques in navigation, the influential factors of cyber threats should be tackled appropriately.

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