Risk Analysis of Ship Foundering Using the Hybrid Causal Logic Methodology

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Abstract: Ship foundering usually poses a significant threat to the crew and property on board. This paper aims to determine the important chains of events leading to accidents and to provide precautionary measures. To conduct ship foundering risk analysis, this paper adopts a method called hybrid causal logic (HCL), which combines fault trees (FT) and Bayesian belief networks (BBN) to better model human and organizational factors in ship foundering accidents. First, factors causing the ship foundering are extracted from accident reports and are used to establish an event sequence diagram (ESD) model. Then, nodes representing human and organizational factors in ESD are analyzed using BBNs. Other nodes in the ESD model are dealt with by FT, in which the basic events representing human and organizational factors are also examined using BBNs. Combining the results derived from FT and BBN models, the established ESD is used to evaluate the risk of ship foundering in context of different scenarios, and to sort the chains of events in a specific scenario in line with the value of probability. Finally, an illustrative example is given to verify the approach and to demonstrate its practicality and effectiveness in risk analysis of ship foundering.

Keywords: Ship foundering, Hybrid causal logic methodology, Fault tree, Bayesian belief network.

1. INTRODUCTION

With the “Belt and Road” and the “Yangtze River economic zone” policy proposed and promoted by China, the status of transportation and logistics has become increasingly prominent, thus the importance of water transportation has also gone up. Although the share of water transportation in the world today decreases slightly as other forms of transportation are developed, its large size and growing traffic demand in the world as well as its low cost, lead to that water transport system is still huge, deserving attention. Different from road transportation, the consequences of water traffic accidents are very serious. Once occurs, it may be a very serious accident. According to the statistics of Ministry of Transport of the People's Republic of China (MOT), a total of 196 cases of maritime traffic accidents occurred in China in 2016. There were 203 deaths and 82 wrecks [1]. The loss was very serious.

Ship foundering is one of the typical scenes of water traffic accidents, whose serious consequences are worth our attention. Numerous studies have been conducted on water traffic accidents. Zhang [2] established a nonlinear single degree of freedom differential equation of ship rolling from the energy perspective. This work Transformed the random wave-induced moment from time domain to frequency domain using FT, and extended the random Melnikov function and the rate of phase flux to effects of navigation speed and heading angle, finally quantified the safety degree of a ship against foundering. Pivert [3] had conducted an analytical calculation of the probability density function of the variables involved in the roll motion following a Markov method. The ship foundering probability could be calculated if the characteristics of the roll motion during the capsizing is known. Wang [4] developed the simulation programs of ship rolling in the beam wind and wave under extreme conditions to calculate the ship-capsizing probability, using the mathematical model with one degree of freedom. Lee [5] used highly advanced Modeling & Simulation (M&S) system of Fluid-Structure Interaction (FSI) analysis technique of hydro code LS-DYNA to ship foundering. Wang [6-8] proposed a new quaternion ship domain(QSD), a more practical fuzzy quaternion ship domain(FQSD), a dynamic quaternion ship

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domain(DQSD), an intelligent quaternion ship domain(IQSD) and a generalized intelligent quaternion ship domain(GIQSD), and these ship domains are all used in assessment of spatial collision risk for ship encountered. Based on comprehensive simulations, these ship domains are demonstrated more reliable and flexible than before. Xiao [9] analyzed the Eastern Star ferry accident by 24Model, which is an accident causation model based on system thinking. Wu [10] proposed a modified cognitive reliability and error analysis method (CREAM) for estimating the human error probability in the maritime accident process on the basis of an evidential reasoning approach. Jiang [11] also predict human reliability of ship pilot using CREAM model. Liang [12] proposed an assessment model for ship foundering accidents in inland waters search and rescue operations based on Bayesian network technology and expert surveys.

In the literature review, the risk of ship foundering was analyzed from the mathematical method to the simulation, and the safety field model. However, it is unable to clearly and comprehensively discuss human and organization factors, and non-human factors. Recently, a methodology called hybrid causal logic (HCL) has been developed [13], allowing Bayesian Belief Networks (BBNs) to provide input information to fault trees (FTs) and event sequence diagram (ESD). In this way, the impact of some difficult-to-quantify human factors on accidents can be integrated into a complete accident model. Zhu [14] presented a framework to integrate software behavior into probabilistic risk assessment. Mohaghegh [15, 16] incorporated organizational factors into probabilistic risk assessment (PRA), extended the PRA framework to include the effects of organizational factors. Roed [17] used the methodology to offshore risk analysis, he has presented the application of HCL framework to the offshore oil and gas industry. Groth [18] used the methodology to aircraft taking off from the wrong runway. The methodology can be used in different areas to assessment the risk of that system.

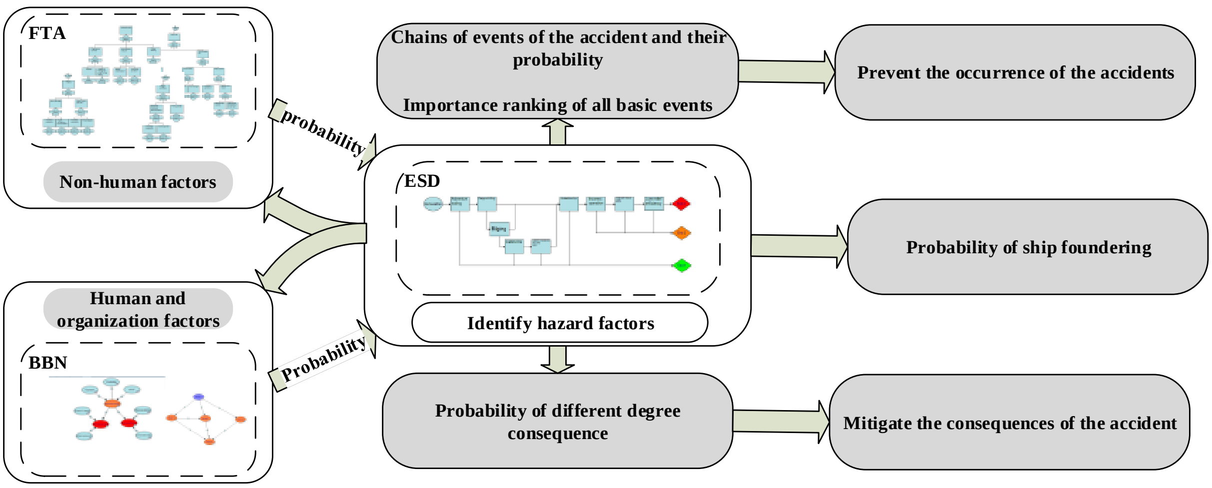
Therefore, in this paper, HCL methodology is introduced into analyzing ship foundering accident, the whole process of accident is evolved using ESD model, FT is used to analyze some safety barriers in ship foundering accidents, BBN is used to quantify human and organizational factors and provide information to FTs and ESD. Through expert knowledge and empirical data, we can make up for the problems of human factors data and information missing.

The paper is organized as follows, In Section 2, we present an introduction to HCL methodology, and then present the procedure of it. Section 3 presents a case study on ship foundering, followed by discussion in Section 4 and conclusions in Section 5.

2. HYBRID CAUSAL LOGIC METHODOLOGY

To analyze ship foundering accidents, a methodology HCL is utilized in this paper. In this methodology event sequence diagrams (ESD), fault trees (FT), and Bayesian belief networks (BBN) were integrated. The process and framework of the methodology are shown in Figure 1.

Figure 1 Framework and Flowchart of The Model



In the utilized HCL, the ESD model depicts different scenarios of ship foundering accidents. Probabilities of different consequences of the accident could be estimated. In certain accident scenario, FT and BBN models are used to model several risk influence factors that lead to such an accident. In this way, the probability of some risk influence factors such as cargo shifting, bilging, cabin fire, water for fire-fighting left in the cabin and emergency disposal is identified and estimated.

2.1. Event Sequence Diagram

ESD is a graphical, probabilistic approach to model and analyze accidents. ESD is an inductive method that uses positive logical reasoning, and the result of ESD gives a list of possible accidents that result from some particular hazard event. The concrete modeling method is a systematic technique. The first step is to identify an initiating event. Then the initiating event can be tracked to different damage situations. There are many initiating events that have caused an accident, including human and organizational factors, and non-human factors.

This paper quantifies the failure of nodes in ESD by FT and BBN. The probability of the top event in a FT is evaluated using a combination of logic gates of multi-level connections up to the basic event probability. The probabilities of human factors are evaluated by BBN. Finally, the probabilities of different accident scenarios in ESD can be obtained.

<u>Event Sequence Diagram Analysis</u>

Assume that multiple critical events are respond sequentially to the appearance of an initiating event (IE), the output is binary, success or failure. For the ESD analysis, factors harmful to the system will evolve to varying degrees of consequences as the accident progresses. When entering the failure and success probability of all the key event, the probabilities of different accident results can be obtained.

<u>Procedure for Accidents Scenarios</u>

Step 1: After the initiating event, check the status of nodes (such as Cargo shift, Bilging, Cabin fire. etc.) in order;
Step 2: Skip to Step 4, if the event fails;
Step 3: Skip to Step 5, if the event is not invalid;
Step 4: Move to the next node, repeat Step 1;
Step 5: Obtain the probability of all consequence, FT and BBN analysis are used to calculate the success and failure probability of all nodes not obtained directly.

2.2. Fault Trees

This paper models the process of generating branches of some ESD nodes using fault trees. The modelling of the fault tree aims to obtain the “true” output of the binomial partition of ESD model. For some non-human factors turning events in ESD, the event is linked to the FT as the top event, the probability of the event is “true” is a conditional probability given by the FT.

<u>Fault Tree Analysis</u>

It is assumed that the failure of each of the node in the ESD is statistically independent. AND gates and OR gates in FT describe the interaction of the top event (failure of a node or component in ESD) and changes in the state of a sub-event. These two kinds of logic gates are used to build a FT. For FT analysis, the probability of a top event can be quantified.

<u>Procedure for Fault Tree Analysis</u>

Step 1: Build fault trees based on top events and functional logic;

Step 2: Boolean algebra is used to simplify fault trees, and minimum cut sets can be obtained;
Step 3: According to the probability of basic events, the probability of top events could be quantified, and the importance of the basic events which caused the top events can be obtained.

2.3. Bayesian Networks

This paper uses the Bayesian networks to quantify the human and organizational factors, because these factors are difficult to quantify in ESD and FT.

<u>Bayesian Network Analysis</u>

The Bayesian network is a graphical model that describes the causal relationships between the key factors in a system and one or more final outputs. The network consists of nodes and directed arcs. Nodes in BBN represent states or conditions, and arcs in BBN represent the immediate impact between nodes. Similar to the FT, BBN can also quantify the probability of the node in ESD.

<u>Procedure for Bayesian Network Analysis</u>

Step 1: Identify all relevant factors that have a significant impact on the output events, the output events represent human and organizational factors in ESD and FT;
Step 2: Model the BBN according to the logical relationships between different risk influence factors;
Step 3: According to the existing data and Bayesian networks to establish a conditional probability table (CPT), enter the corresponding conditional probability;
Step 4: Calculate the probabilities of nodes in ESD or basic events in FT.

In this methodology, given the probability of each basic event in FT and BBN, the failure probability of every node in ESD could be calculated using quantitative FT and BBN. In this way, the cause of consequence could be expressed by the chains of basic events. These chains of events could be ranked according to their probabilities. The importance of the chains of events can be figured out.

In addition, four importance measures are adopted to provide the information about criticality of the basic events according to their contribution to the overall system performance. These four importance measure are Birnbaum importance measure, Fussell-Vesely importance measure, risk achievement worth (RAW) and risk reduction worth (RRW).

Birnbaum importance measure was presented by Birnbaum in 1969. Birnbaum importance measure of a basic event i is [19]:

$$I^B(i \mid t) = h(1_i, p(t)) - h(0_i, p(t)) \qquad (1)$$

The basic event is in two states when measured by Birnbaum importance measure. $h(1_i, p(t))$ represents a state: the system and the basic event i are both reliable. $h(0_i, p(t))$ represents the system's reliability with the basic event failed. The larger the value of I^B of a basic event, the basic event is considered more important in the system.

The RAW and RRW importance measures were presented by Cheok in 1998 [20]. The RAW and RRW importance measures can be observed as measures from Birnbaum importance measure. Let $h(p(t))$ represent the real system reliability. Then, using previously introduced notation, RAW and RRW can be defined as follows [17]:

$$I^{RAW}(i \mid t) = \frac{1 - h(0_i, p(t))}{1 - h(p(t))} \qquad (2)$$

$$I^{RRW}(i \mid t) = \frac{1 - h(p(t))}{1 - h(1_i, p(t))} \qquad (3)$$

Fussell-Vesely importance measure was presented by Vesely in 1983 [21]. It relies on minimal cut sets, and assumes that the basic event has an influence on system failure only when some of the minimal cuts, to which their failure event belongs, occur. Let $Q_i(t)$ denote the probability that *j*-th minimal cut which contains the basic event *i* occurs at a time *t* and $Q(t)$ denotes the real probability of the system failure. Fussell-Vesely importance measure of the basic *i* is [18]:

$$I^{FV}(i\,|\,t) \approx \frac{1-\prod_{j-1}^{m_i}(1-\breve{Q}_i^{\,j}(t))}{Q(t)} \approx \frac{\sum_{j-1}^{m_i}\breve{Q}_i^{\,j}(t)}{Q(t)} \qquad (4)$$

3. CASE STUDY

An ESD model presented in this paper was based on analyzing accident reports, refined the key factors that led to the ship foundering accident, relied on the logic of safety analysis. The key factors were extracted as nodes in ESD, forming the ESD model according to the logical relationship of these nodes.

3.1. Initiating Events of ESD Model

There are many initiating events having caused ship foundering accidents, including human and organizational factors, and non-human factors such as environment and mechanical problems. Table 1 shows some factors that may be an initiating event. Based on the study of accidents reports and the refinement of key causal events, bad weather is a very important initiating event may lead to ship foundering accidents. This paper thus attempts to study the probability of ship foundering under bad weather conditions.

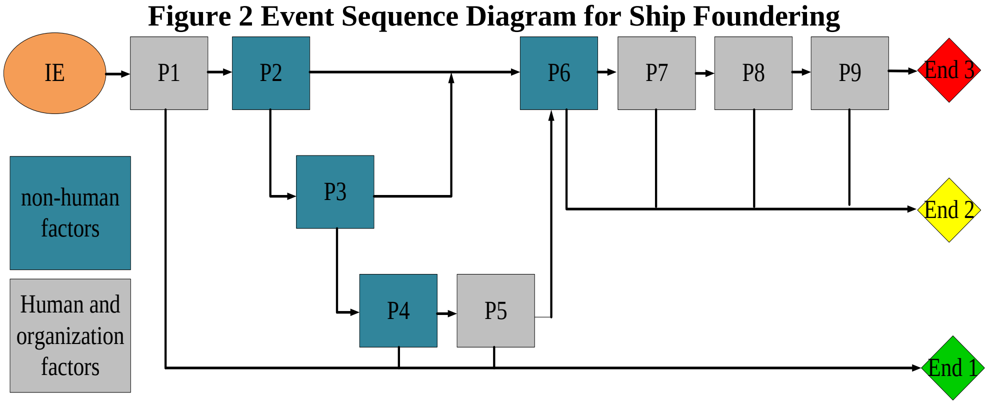
Table 1 Initiating Events

Broad factors involved	Initiating events
Human factors	Incorrect operation
	Incompetent crew
	Crew lack of professional training
Other factors	Cabin-fire
	Bilging
	Cargo shifting
	Bad weather

3.2. Event Sequence Diagram Analysis

Figure 2 shows the evolution of a ship's foundering accident in bad weather. It deals with several key causes of ship accidents in bad weather, including incorrect operation, cargo shifting, water left in cabin, low efficiency of rescue and so on.

Figure 2 Event Sequence Diagram for Ship Foundering



Compared to the clear weather, a ship sailed in bad weather is in a dangerous state. Failure of any safety barrier, such as cargo shift, may cause the ship to be unstable. If the stability of the ship is lower than the lowest stability of the navigation to against the bad weather, she may be in a very dangerous position, and she may be easy to capsize; if the crew's emergency operation is not appropriate, the ship may high likely capsize. If the crew members have weak self-rescue ability, the relief efficiency of the outside world is low, it may lead to a very serious ship foundering consequence, such as Figure 2 (End3). If the crew's operation is appropriate, the crew members have better self-rescue ability or higher rescue efficiency, the consequence of ship foundering may not so serious. The consequence shows in Figure 2 (End2).

The data for the nodes in ESD comes from (1) assumptions, (2) statistical information [1], (3) FT models, (4) BBN models, which are given in Table 2. As part of data is hard to collected, some safety barriers' probabilities in this paper were given directly by experts.

Table 2: Nodes of ESD Model

Node	Name	Probability	Sources
IE	Bad weather	0.167	China MSA statistics
P1	Sailing	0.20	Assumed 0.20
P2	Cargo shift	Linked to FT	Given by experts 0.01
P3	Bilging	Linked to FT	Assumed 0.10
P4	Cabin fire	Linked to FT	Calculated 0.11
P5	Fire water left in the cabin	Linked to BBN	Given by experts 0.20
P6	Unstable ship	Linked to FT	Calculated 0.20
P7	Emergency handling capacity	Linked to BBN	Calculated 0.11
P8	Self-rescue ability	Linked to BBN	Calculated 0.09
P9	Rescue efficiency	Linked to BBN	Calculated 0.39

Based on accident and incident reports, each node in the ESD model is defined as follows:

1) Bad weather(IE):
Bad weather often affects the ability of crew to control the ship, then it may lead to accidents, although the natural environment is not usually the direct cause of the accident. Extreme bad conditions not only decrease visibility but also increase difficulties in controlling a ship. In addition, extreme weather makes it difficult for deck officers accurately keeping the ship stable. At the same time, bad weather makes it very difficult for crew members to save themselves, and bad weather may greatly increase the difficulty of search and rescue.

2) Cargo shifting(P2):
If a ship is subject to strong winds or storms, the ship's cargo may move in position, which may cause the ship's stability to be deteriorated and even cause an accident. Under no circumstances should the cargo be loaded or ballasted so that the stability of the vessel is threatened. The stability of the ship is essential to the safety of the crew, the cargo, and the environment. If the stability of the ship is too high or too low, the safety of the ship may not be guaranteed.

3) Bilging(P3):
Due to the crew's non-compliance with regulations, sometimes the hatch of ship is unsealed. Under the attack of a large storm, the water entering the hold through the unsealed hatch or breakage leads to an increase in the volume of water in the hold, resulting in the ship slipping out of stability.

4) Cabin fire(P4), Fire water left in the cabin(P5):
The increase of ship fire accidents over the years has posed a great threat to the safety of ships, cargoes, and even people on board. Cabin fire is a common marine accident risk factors. Cabin fires not only spread rapidly but also have serious devastating [1]. If water for fire-fighting is not handled properly, the water remains in the cabin after extinguishing the fire. Under bad weather conditions, the ship's stability may be deteriorated, and further ship capsize may occur.

5) Human and organizational factors (P1, P7, P8, P9):
Accident statistics show that human and organizational factors caused too many accidents [22]. Some enterprises are driven by economic interests, and they often ignore the training of crew safety, resulting in poor professional skills of the crew, a lack of safety awareness and easy operation incorrectly under pressure, the crews cannot meet the safety requirements of waterway transportation. A crew who doesn't have professional train is easy to operate incorrectly when the ship is in distress. In this way, it will increase the possibility of ship capsize. In addition, when the ship begins capsizing, whether seriousness or not, the very important factor is rescue ability. If the accident was controlled in time, the hazard of the accident can be greatly reduced.

6) Consequence (End 1, End 2, End 3):
End 3 in the ESD model represents a serious consequence. In this scenario, ship's ability to resist ship foundering accidents is under the limits, and no measures are taken to prevent the accident. If the various safety barriers in ESD are not failed, the ship is safe. This scenario corresponds with End 1. End 2 is between End 1 and End 3. In this scenario, ship's ability to resist ship foundering accidents is under the limits, but some measures are adopted to mitigate the consequences of the accident.

3.3. Fault Tree Analysis

Figure 3 shows an example of Fault tree, which is one of the safety barriers in response to the development of a ship's foundering accident. The probability of failure of the node is estimated using the procedure mentioned in the previous section. The bottom nodes in Figure 3 are the basic events that leads to the failure of the intermediate event, and they are finally used to represent the top event. With the probabilities of human and organizational factors in ESD model quantified by BBN, the minimum cut sets and the probability of the top event can be calculated according to FT analysis.

Figure 3: Fault Tree of Unstable Ship

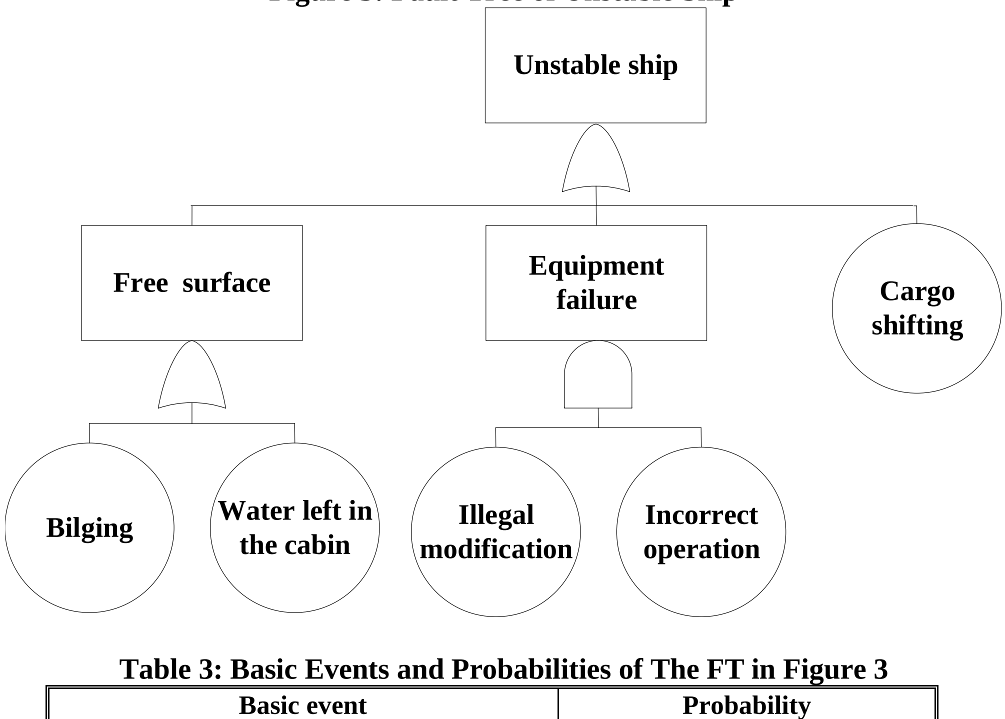


Table 3: Basic Events and Probabilities of The FT in Figure 3

Basic event	Probability
Bilging	Linked to FT
Water left in the cabin	Linked to FT
Illegal modification	Assumed 0.2
Incorrect operation	Linked to BBN
Cargo shifting	Given by experts 0.01

3.4. Top Hazard Probability

In this specific case, Top Hazard Probability is the probability of the ship foundering accident in bad weather. The probability can be estimated using the method mentioned in section 2. Taking into account the failure criteria for each of the consequence of the ESD analysis, the probability of a branch or component is calculated by FT and BBN. The probability of ship foundering in bad weather is obtained.

3.5. Bayesian Network Analysis

Figure 4 is an example of a human factor's quantification using BBN, the BBN model is used to quantify the probability of P8 in ESD. The following parameters of this BBN in Figure 4 contain: Visibility, Current, Wind, Natural environment, Self-saving equipment, Overturn speed, Self-rescue ability. These parameters are from 28 foundering accidents reported according to China MSA. Moreover, 4 experts from Tianjin MSA were interviewed. They provided their opinions on the dependency among indicators according to their experience, which can be treated as a reference. The dependencies among the indicators are illustrated as follows. Table 4 shows the nodes in Bayesian networks.

Figure 4 BBN of Self-Rescue Ability

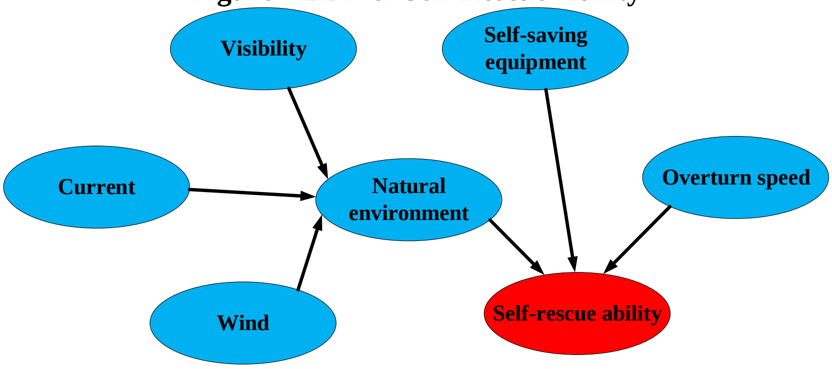


Table 4 Nodes of BBN

Nodes of BBN	Level	
	L1	L2
Visibility	Good	Poor
Current	Gentle	Rapid
Wind	Below scale-4	Above scale-4
Natural environment	Good	Bad
Self-saving equipment	Good	Poor
Overturn speed	Slow	Quick
Self-rescue ability	Good	Poor
Communication state	Good	Poor

Based on the BBN structure, the inference of consequences can be made using prior distributions of root nodes and the CPTs of child nodes. The prior distributions of all root nodes can be obtained from the statistics of accidents. The CPTs of "Natural environment" and "Self-rescue ability" given by experts and accident reports are shown in Tables 5 and Table 6.

Table 5 CPT of "Natural environment" Given the "Visibility", "Current" and "Wind"

Visibility		Good				Poor			
Current		Gentle		Rapid		Gentle		Rapid	
Wind		Below scale-4	Above scale-4	Below scale-4	Above scale-4	Below scale-4	Above scale-4	Below scale-4	Above scale-4
Natural environment	Good	1	0.4	0.45	0.3	0.5	0.3	0.35	0
	Bad	0	0.6	0.55	0.7	0.5	0.7	0.65	1

Table 6 CPT of "Self-rescue ability" Given the "Self-saving equipment", "Natural environment" and "Overturn speed"

Self-saving equipment		Good				Poor			
Natural environment		Good		Bad		Good		Bad	
Overturn speed		Slow	Quick	Slow	Quick	Slow	Quick	Slow	Quick
Self-rescue ability	Good	1	0.4	0.7	0.3	0.45	0.2	0.1	0
	Poor	0	0.6	0.3	0.7	0.55	0.8	0.9	1

4. RESULT AND DISCUSSION

This paper deals with the application of this methodology in the safety improvement of ship foundering accidents. As shown in Table 7, the probability of a serious ship foundering accident is very low under bad weather condition. However, it is still possible for a ship foundering accident. Due to the particularity of water transportation accidents, the consequences of it are always very serious. Therefore, we should take some measures to resist the ship foundering accident.

Table 7 Probability of Different Consequence

Ranking	Consequence	Probability
1	Safe	0.0537879
2	Light consequence	0.0018281
3	Serious consequence	0.0000507

Table 8 Chains of Events of Ship Foundering

Ranking	Chains of Events		
1	Bad weather, Adventure sailing	Liquefaction of cargoes	Bad emergency handling capacity, Poor self-rescue ability, Low rescue efficiency
2		Incorrect operation	
3		Incorrect operation, Tough navigation environment	
4		Incorrect operation, Ship defects	
5		Equipment short circuit, Incorrect operation	
6		Equipment overload, Incorrect operation	
7		Combustible goods, Incorrect operation	
8		Fuel leakage, Incorrect operation	
9		Combustible goods, Mechanical temperature is too high, Incorrect operation	
10		Combustible goods, Incorrect operation	
11		Fuel leakage, Mechanical temperature is too high, Incorrect operation	
12		Fuel leakage, Incorrect operation	

Bad weather was taken as initiating event, and then a ESD model was used to evolve to different consequence, so some important chains of events of the accident can be calculated. In Table 8, the chain of events and the probability of them are shown. In all the chains of events, risk of the chain of events is highest which contains: bad weather, adventure sailing, liquefaction of cargoes, bad emergency handling capacity, bad self-rescue ability and low rescue efficiency. Followed chain of events which contains: bad weather, adventure sailing, incorrect operation, bad emergency handling capacity, bad self-rescue ability and low rescue efficiency.

Table 9 shows the importance measure of every component in the ship foundering model. The rankings were based on four importance measures: Birnbaum, RAW, RRW, and Vesely-Fussel, respectively. The rankings showed that Liquefaction of cargoes was a main risk in the ship foundering accident in bad weather, along with incorrect operation, which is consistent with the result of the chain of events. These measures should be accepted in order to minimize the probability and reduce harm consequence of those undesired events：(i) Monitoring the indicators related to the risks identified in this model (cargo shift, bilging, cabin fire, water for fire-fighting left in cabin and so on). (ii) Training crew members involved in vessel sailing regularly. (iii) Inspiring crews for the efficient and responsible ship safety management. (iv)Increasing the awareness of the importance of ship foundering.

Table 9 Importance Measures Results

NO	Basic event	RAW	Vesely-Fussel	RRW	Birnbaum
1	Illegal modification	1	0.22	1	0
2	Incorrect operation	1.30488	0.5	1.307611	0
3	Equipment short circuit	1.22295	0.034243	1.006464	0.002127
4	Equipment overload	1.22295	0.017121	1.003176	0.002097
6	Mechanical sparks	1	0.056	1	0
7	High mechanical temperature	1	0.07	1	0
8	Tough navigation environment	1.182777	0.390317	1.098931	0.00253
9	Ship defects	1.218298	0.097464	1.01935	0.002201
10	Liquefaction of cargoes	1.455579	0.655011	1.594252	0.007682
11	Solid cargoes	1.141387	0.627763	1.208906	0.002914
12	Combustible cargoes	1.125084	0	1	0.00116
13	Fuel leakage	1.125084	0	1	0.00116

The result of the model can help managers to grasp many important risk influence factors and the importance of them. Therefore, the managers can combine it with economic operating costs, and the managers can improve the safety of ship with less cost.

The biggest limitation of this paper was the lack of data of the process of ship foundering. In this paper, the experts' evaluations, accident reports and China MSA statistics were used in order to estimate the probability of ship foundering in bad weather. Further work could use more reliable data to improve it. What's more, except the safety barriers mentioned in this paper, some new safety barriers could be got. Despite limitations, the result of this model has clearly shown some important risk influences factors. Some measures can be adopted to prevent the occurrence of ship foundering accidents and mitigate the consequences of the accident.

5. CONCLUTION

In this paper, a hybrid causal logic method is applied to analyze ship foundering accidents. Based on HCL methodology, it can be evaluated that the risk of ship's foundering accidents in bad weather conditions, and the measures can be obtained that how to improve the safety performance of ships against foundering accidents. The first part of the methodology includes analyzing the risk probability of ship foundering accident using the ESD model. The second part of the methodology uses FT to analyze the Safety barrier represented non-human factors. The third part of the methodology is the use of Bayesian networks in the analysis of human and organizational factors. BBN modeling aims to quantify the human and organizational factors, which are always difficult to quantify. Finally, the chains of events of ship foundering accident and the importance rankings of basic events can be obtained from the model, these results may be useful in enhancing the reliability of weaker safety barriers. In this way, the probability of ship foundering can be reduced. The example presented in this paper provides new insights into improving the safety of foundering accidents during ship navigation. In future, this study may be extended to analyze the probability of other accidents and to propose countermeasures.

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