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RISK ANALYSIS OF SHIP COLLISION IN INDONESIAN WATER USING HOUSE OF RISK

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Abstract

Marine transportation is supporter of the world trade. Even though the regulation had been implemented, marine transportation still has risks in the voyages. One of the risks is ship collisions. The purpose of this study to identify the root causes of ship collisions in Indonesian waters and identify preventive action to reduce the ship collision. The study based on forty- six collisions occur between 2010 till 2018. This study uses House of Risk Method. The House of Risk (HOR) consists of two phases. The House of Risk Phase 1 is deployed to reveal the risks agent of the accidents. and the analysis risk agents which critical category. The House of Risk Phase 2 developing measures to mitigate the risk agent critical category. Risk agent critical category is root cause of ship collisions. The root cause of ship collision in this study is crew recruitment process is not accountable, Shipping company does not implement appropriate maintenance plan, and clearance out letter approved without inspection to the ship. The preventive actions are creating a system and using technology to ensure shipping companies provide up-to-date information about the ship's condition, create a system and use technology in assessing sea-worthy requirements, create a system to ensure the crew on board have appropriate competence, create a system to ensure shipping companies carry out the selection process in crew recruitment, and create a system to ensure shipping companies conduct competency tests on crew recruitment. Stage of crew preparation, and voyage preparations are the most critical stages to be aware, in order to reduce of ship collision should be to create a system in the crew recruitment procedure at the crew preparation stage and create a system in the clearance out procedure at the sailing preparation stage. The conclusion of this study is the ship collision caused by a combination of several interrelated causal factors, so that to minimize the risk of ship collision have to take a systems approach.

Keywords: House of Risk, Risk agent, Risk event, Ship collision.

1. Introduction

Marine transportation is an important role in the world trade. The capability of ships to carry cargoes and to connect centre of economic make the marine transportation an enabler in the world economy. Marine transportation carries more than 80% cargoes who traded in worldwide. Even though marine transportation has an important role, transportation still carries risks, whether the ship in voyage or the ship at the port [1, 2]. Preventive action to improve marine transportation safety still need to be taken to reduce the accidents [3]. One type of accidents is ship collision which might cause loss of life, loss or damage of cargoes and environmental disaster.

Protection of ship crew, environment, ships, and cargo has a central role in shipping safety system. Through regulations, empowerment of human resource and deployment of appropriate technologies will form a shipping safety system to reduce and prevent accidents. Nevertheless, accidents remain difficulty to be avoided, as its possibility to happen is always around us. The priority of marine transportation is to guarantee safety and comfort. Safety of ship operations have to following criteria consisting of first the ship must comply regulation regarding design, materials, equipment, building procedures. Second, the ship must be operated well safely. A collision is often an outcome of a navigation problem. The rules how to navigate the ships has been set out in the International Regulations for Preventing Collisions at Sea 1972 (COLREG), in order to prevent collision between two or more vessels.

Nevertheless, recorded forty-six collisions have occurred between 2010-2018 in Indonesian water. In most cases, collisions involve loss of life, loss or damage of cargoes and environment [4] categorize the causes of ship accidents into human error, technical and mechanical failure, and environmental factors. On top of the above, another finding shows that a ship accident could cause more, namely political, economic damage. An accident affects several entities in the maritime industry, such as shipping companies, flag states and insurance [5]. An accident analysis can provide information on the root causes of ship accidents. By doing so, we could identify ways to control risks [6].

A number of studies on ship accidents shows various factors which have caused shipping accidents Most of the collisions accidents are caused by bad visibility (environmental factors), wrong decision making, poor communication between ships or between bridge crew (Bridge Resource Management), the crew does not focus during watchkeeping and does not comply with the Safety Management System [7].

Sotrialis et al. [8] developed a Bayesian Network model to identify the most important factors in collision probabilities. He concluded the collisions depend strongly on human factors. The main source of human error leading mostly to a collision accident is the poor monitoring and control of traffic conditions while on watchkeeping. Yildirim et al. [9] in their study found the most important causes of accidents are unsafe actions and their triggers. The undisciplined crew on watchkeeping, poor communication, and poor bridge resource management are the main causes of the collision accidents (discipline, communication, coordination, skills, the number of crew on duty). Hyungju et al. [10] studied on the MV SEWOL accident showed the accidents could occur if the organization failed to identify the ability of the crew and placed the crew that could not to handle dangerous situations on board. Graziano et al. [11] apply Technique for the Retrospective and Predictive

Analysis of Cognitive Errors (TRACER) to identify the human error in collisions. He delivers a procedure to identify the human errors by measuring the performance of ship operations. Furthermore, ship safety encompasses aspects from design state to the operations. Inappropriate design, construction which are typical in traditional shipbuilding, poor implementation of regulations and operations of ships are exposed to the safety risks which might lead to ship accidents [12]. The National Transportation Safety Committee of Indonesia states that the causes of ship accidents are bad weather, fires due to dangerous loads, overload, shifting loads, imperfect ship design and human error.

The above studies mostly presented the "upper level" causes of accidents. In order to make the risk analysis practically useful, a government authority or a shipping company prefers a list actionable activity, as a set of measure to reduce ship accidents. Unfortunately, the above findings are less adequate to be immediately translated into steps of actions. It remains unclear the direct and indirect causes of accidents. This paper aims to identify the root causes or risk agent critical category of ship collisions, and identify preventive action to reduce the root cause, by using the House of Risk.

2. Method

The House of Risk modifies Failure Models and Effect Analysis (FMEA) model for risk quantification. It adapts the home quality model (HOQ) to prioritize risk agents that have to handle first and to choose the most effective actions to reduce the risks that potentially arise from risk agents. A risk agent is a factor that is viewed as the root cause of triggering a risk event, this is in many cases an indirect cause of an accident. A risk event is a situation which is viewed as a direct cause of an accident [13].

The House of Risk method involves the process of identifying, assessing, planning and implementing solutions. This method is innovative, integrated and simple. HOR analysis uses the approach of calculating the Risk Priority Index for selecting the main risk and then entering it into the House of Quality. The House of Risks (HOR) consists of two phases, namely HOR Phase 1 and HOR Phase 2. HOR Phase 1 to identify, analyse and measure potential risk by prioritizing critical risk agents, Then, HOR Phase 2 to evaluate critical risks, and identify the most effective preventive action [13]. The analysis House of Risk follows the following procedure [13].

A. House of Risk Phase 1

- Identification risk event and risk agent.
- Assessment of severity of risk event.
- Assessment of occurrence of risk agent.
- Assessment of relationship between risk events and risk agent.
- ARP (Aggregate Risk Potential) calculation.
- Identification critical risk agent, and root cause of ship collisions.

B. House of Risk Phase 2

- Identification of preventive action.

- Assessment of Relationship between root cause of ship collisions and preventive action.
- Assessment of level of difficulty to implement preventive action.
- Calculate Effectiveness to Difficulty Ratio.
- Calculate the value of effectiveness to difficulty.
- Evaluation the most effective preventive action

Assessment of severity of risk event, assessment of occurrence of risk agent, assessment of relationship between risk events and risk agent, assessment of relationship between root cause of ship collisions and preventive action, and assessment of level of difficulty to implement preventive action are obtained through interviews and questionnaires by shipping experts as respondents. Respondents are determined based on educational background, occupation, and work experiences in shipping business. There were 40 Respondents consist of 9 NTSC investigators, 3 juries of Maritime Court, 6 Marine inspector officers, 3 Harbour master officers, 2 Superintendents, 1 DPA, 3 Captains, 2 Marine engineers, 1 Chief Officer, 1 Third Officer, 2 machinist, 5 lecturers in maritime education, 2 practitioners in maritime education.

The number of respondents was taken by considering time, limited funds, and respondent's expertise. In addition, the number of respondents in the study should be between 30 and 500, and the number of respondents that are suitable for use in the study is between 30 and 500 [14].

2.1. House of Risk Phase 1

The House of Risk Phase 1 evaluates the occurrence and severity. Severity shows the level of disruption or damage which could be caused by a risk event. Occurrence is a probability a risk agent might occur. In order to obtain the critical risk agents, a correlation between the severity of risk events and the occurrence of risk agents are to be computed. This method also evaluates the Aggregate Risk Potential (ARP). ARP is obtained through the value of severity of risk events, the probability of occurrence of risk agents, and the level of relationship between risk agents and risk events [13].

2.1.1. Identification of risk events dan risk agents

It starts with selecting a ship collision cases. From every accident, it is to be identified events which might lead directly to the above accident, which are called risk events. Then from every risk event, it is to be identified situations or objects, called risk agents, which could potentially lead to a risk event.

2.1.2. Severity assessment of risk events

The criteria of the assessments are the damage of the ship, cargo and human lives. The degree of severity obtained from the questionnaire and interviews is qualitative and converted into a numerical scale from 1 till 4 dan grouped into four categories.

- Low category is the ship collision contribute to ship damage $\leq 50\%$, the criteria is given value of 1.

- Moderate category is the ship collision contribute to ship damage ≤ 50% and load damage ≤ 50%, the criteria is given value of 2.
- High category is the ship collision contribute to ship damage ≥ 50% load damage ≥ 50%, the criteria is given value of 3.
- Very high category is the ship collision contribute to 100% loss of ship, 100% damage/loss of load, and fatalities. the criteria are given value of 4.

2.1.3. Occurrence assessments of risk agents

Similar to the above, the information obtained the respondents are qualitative. A conversion to a numerical scale from 1 to 4. The occurrence assessment is based on the number of ships collision within one month. The assessment level is categorized into four levels. The categories are:

- Rare category is the ship collision occurred one time in a month, the category is given value of 1.
- Moderate category is the ship collision occurred twice in a month; the category is given value of 2.
- Often category is the ship collision occurred three times until five times in a month, the category is given value of 3.
- Very often is ship collision occurred more than five times in a month, the category is given value of 4.

2.1.4. Relationship assessment between risk events and risk agent.

They build a relationship matrix between risk events and risk agents with a value of {0,1,3,9}. It aims to measure the level of relationship between risk events and risk agents. The relationships between risk events and risk agents use a numerical scale from 0 to 9. The relationship assessment categorized into four levels of relationship, no relationship is given a value of 0, weak relationships are given a value of 1, the moderate relationship is given the value of 3 and strong relationships are given a value of 9. No relationship means that a risk agent does not cause a risk event.

2.1.5. Aggregate Risk Potential (ARP) calculation

ARP value describes the level of consequences caused by a risk agent. The value of the ARP is computed use the following formula:

$$ARP_j = O_j \times \sum(S_i . R_{ij}) \quad (1)$$

where ARP_j is the Aggregate Risk Potentials of a risk agent, O_j is occurrence of the risk agent, S_i is severity of the risk event, and R_i is relationship between a risk event and a risk agent. After that Rank the risks agents from the highest *ARP* value to the lowest *ARP* value.

2.1.6. Identifying critical risk agents

For practical purposes, most risk events are very likely triggered by only a very few risk agents. Identification risk agent critical category use the pareto Chart. The Pareto Chart is applied to identify risk agent of critical categories that are priority

problems. In use, the pareto Chart has 80-20 rules. The rule has the understanding that about 80% of the effects caused by 20% of the problem causes.

2.2. House of Risk Phase 2

The House of Risk phase 2 is used for risk treatment which gives priority to practical preventive actions to reduce the root cause. Preventive action requires consideration of choices and creative design. Preparation of preventive action should consider resources that include funds, people, time, facilities and infrastructure [13].

2.2.1. Identification of preventive action

Identification of preventive action based on the classification of the risk agent critical category or the other name root cause of the accident. The purpose of identify preventive action is to reduce the ship collision.

2.2.2. Relationship assessment between root cause of the accident and preventive action.

Assessment of the relationship between the root cause of the accident and preventive action use a numerical scale 0,1,3,9. The relationship assessment categorized into four levels of relationship, no relationship is given a value of 0, weak relationships are given a value of 1, the moderate relationship is given the value of 3 and strong relationships are given a value of 9 [13].

2.2.3. Level of difficulty to implement preventive actions

Assessment is given by shipping experts use a numerical scale 3,4,5. The category into three levels, very easy to implement is given a value of 3, easy to implement given a value of 4, and difficult to implement is given a value of 5 [13].

2.2.4. (*ETD*) Effectiveness to difficulty ratio

ETD is a value that represents preventive action who classified as effective in overcoming critical risks. To calculate the value of effectiveness to difficulty use a formula [15]:

$$ETD_k = TE_k / D_k \tag{2}$$

where ETD_k is effectiveness to difficulty ratio, TE_k is total effectiveness of preventive action, and Dk is the level of difficulty to implement preventive action. The total effectiveness computed by the formula [13]:

$$TE_k = \sum ARP_j . E_{jk} \tag{3}$$

Where *ARP* is Aggregate Risk Potential, and E_{jk} is relationship between root cause of ship collisions and the preventive action.

2.2.5. Evaluation the most effective preventive action

In this step, make rank *ETD* values from the largest to the smallest, and then calculate the cumulative value and cumulative percentage on each *ETD* value. After that identify the most effective preventive action use the pareto Chart. The pareto

Chart has 80-20 rules. The rule has the understanding that about 80% of the effect caused by 20% of the problem.

2.2.6. Validation and Reliability

In this study, the validity carried out through a Forum Group Discussion with shipping experts and used item validity with the Bivariate Person correlation technique. Risk agent, risk event, relationship between risk event and risk agent, and preventive action validated in a Forum Group Discussion with 4 NTSC investigators, 3 juries of maritime court, 1 Captain of the ship, 1 Marine Inspector Officer 1 Harbour master, 1 Marine superintendent and 2 lecturers of maritime education. Result of the severity assessment of risk events, occurrence assessment of risk agents, assessment of relationship between risk events and risk agents, assessment of relationship between root cause of ship collisions and preventive action, and assessment level of difficulty to preventive action validated use Bivariate Person correlation technique.

Reliability test for risk agents, risk events, relationship between risk event and risk agent, and preventive action carried out through interviews with 7 respondents. The same question was given to each respondent at different times to know the consistency of respondents' answer. If the respondents' answer is consistent, the question is reliable. Reliability test for the results of severity assessment of risk events, assessment of occurrence of risk agents, relationship between risk event and risk agent, relationship between root cause of ship collisions and preventive action, and level of difficulty to preventive action used Alpha Cronbach method.

3. Results and Discussion

3.1. Stages in ship operations

The ship operations process is grouped into five stages. The first stage is crew preparation, the processes starting from crew recruitment process until the crew working in the ship. The second step is the ship maintenance. The stage focuses on the treatment on the ship, and how well the shipping company organization manages the ship maintenance. The third stage, cargo handling, consists of activities to ensure a proper loading process including the measures to ensure that the ship possesses a sufficient stability. The fourth stage is a preparation for sail, this stage includes the activities carried out by the shipping company, the captain, the crew, and the inspection of the harbour master to ensure the seaworthiness. The fifth stage is on voyage. This study identifies the risks that can occur at each stage.

3.2. House of Risk Phase 1

House of Risk phase 1 is used to identify category risk agent critical category who are the root causes of ship collisions.

3.2.1. Identification of risk events and risk agents

Risk events and risk agents identified by 46 chronological collisions. Process of accidents is analysed through the chronology, then identified the risk event and risk agents. The list of risk events and risk agents can be seen in Table 1.

Table 1. Identification of risk events and their relevant risk agents.

Remarks on Risk Events	RA Code	Remarks on Risk Agents
Ship in overloaded condition	A1	Crew and harbour master did not have accurate information on quantity of cargo
	A2	Crew did not make stability calculation after loading.
Number and condition of navigation equipment are inadequate	A3	Navigation equipment did not work well.
	A4	Map was not updated.
	A5	Radar was not calibrated.
	A6	Navigation equipment was incomplete and inadequate.
	A7	Crew and harbour master did not check the condition of navigation and ship safety equipment.
	A8	Communication equipment did not work well.
	A9	Shipping company did not implement appropriate maintenance plan.
Crew competence was	A10	Harbour master did not thoroughly check crew's certificate of competency
	A11	Crew recruitment process was not accountable.
Visibility was limited	A12	Weather was bad.
	A13	Environment was dark.
Crew was in doubt during navigating	A14	Crew competence was limited.
	A15	Crew has less sailing experience.
	A16	Crew was not familiar with shipping operation
	A17	Port was a congested.
Watchkeeping was not conducted carefully	A18	Crew in fatigue condition.
	A19	Crew number was less than required by regulation.

3.2.2. Severity of risk events (S)

This assessment involves thirty shipping experts as respondents. The assessment addresses their valuation on how harmful or severe a particular risk event. The scores provided by respondents at the Severity value is shown in Table 2.

Table 2. Result of severity assessment.

Code	Risk Event	Severity (S)
E1	Overload condition	3.10
E2	The number and condition of Navigation equipment was not optimal	2.77
E3	The crew has minimal competence	3.27
E4	Visibility was limited	3.03
E5	Crew doubt in navigating	3.20
E6	The careless crew in watchkeeping	2.73

All risk events in Table 2 have a severity value around of three, indicating that the risk event has a high category. This mean, the risk events have a big impact.

3.2.3. Occurrence of risk agents (O)

This assessment involves thirty shipping experts as respondents. Occurrence of risk agents is fairly of the same level. The scores provided by respondent at the occurrence of risk agent is shown in Table 3.

Table 3. Occurrence of risk agents.

Code	Risk Agent	Occurrence
A1	Crew and harbour master do not have accurate information on quantity of cargo	2.70
A2	Crew does not make stability calculation after loading.	2.53
A3	Navigation equipment does not work well.	2.63
A4	Map is not updated.	2.33
A5	Radar is not calibrated.	2.55
A6	Navigation equipment is incomplete and inadequate.	2.50
A7	Crew and harbour master do not check the condition of navigation and ship safety equipment.	2.33
A8	Communication equipment does not work well	2.57
A9	Shipping company does not implement appropriate maintenance plan.	2.73
A10	Harbour master does not thoroughly check crew Certificates of Competency.	2.17
A11	Crew recruitment process is not accountable	2.57
A12	Weather is bad	2.63
A13	Environment is dark	2.40
A14	Crew competence is limited	2.70
A15	Crew has less sailing experience	2.30
A16	Crew is not familiar with shipping operations	2.40
A17	Port is a congested	2.93
A18	Crew is in fatigue condition	2.43
A19	Crew number is less than required by regulation	2.17

The value of the assessment between 2.17 to 2.93. The value indicated the risk agent in the often criteria. This means, the risk agents often as the cause of ship collisions.

3.2.4. Relationship between risk events and risk agents

Relationship assessment between risk events and risk agents carried out after the risk agent and risk event are identified. The purpose is to assess the level of relationship between risk events and risk agents. The results of the relationship assessment can be seen in Table 4.

Table 4. Relationship between Risk Event and Risk Agent.

RE Code	RA Code	Relationship value	RE Code	RA Code	Relationship value
E1	A1	3	E3	A11	9
E1	A2	3	E4	A12	3
E1	A3	9	E4	A13	1
E1	A4	3	E4	A14	9
E1	A5	9	E4	A15	3
E2	A6	9	E5	A16	1
E2	A7	9	E5	A17	1
E2	A8	1	E6	A18	3
E2	A9	3	E6	A19	1
E2	A10	9			

Based on assessment of relationship between risk agent and risk event (Table 4), there was seven risk agents have value is 9. This means that the risk agents are very strong to cause of risk event.

3.2.5. Aggregate Risk Potential (ARP) assessment

ARP value describes the level of consequences caused by risk. The value illustrates risk agent condition. The result of ARP calculation can be seen in Table 5.

Table 5. ARP value.

RA Code	∑(R*S)	O	ARP value
A1	9.30	2,70	25.11
A2	7.85	2,53	19.90
A3	24.90	2,63	65.57
A4	8.30	2,33	19.37
A5	24.90	2,55	63.91
A6	24.90	2,50	62.25
A7	24.90	2.33	58.10
A8	2.77	2.57	7.10
A9	8.30	2,73	22.69
A10	8.30	2.17	63.70
A11	29.40	2,57	75.46
A12	9.10	2,63	23.96
A13	3.03	2,40	7.28
A14	28.80	2,70	77.76
A15	9.60	2,30	22.08
A16	3.20	2,40	7.68
A17	3.20	2,93	9.39
A18	8.20	2,43	19.95
A19	2.73	2,17	5.92

From the calculation, the highest value is 77.76 and the lowest value is 5.92. Risk agents that have highest value is crew competence is minimal, and the risk agent in lowest value is crew number is less than required by regulation. Risk agent who has highest value is included in critical category.

3.2.6. Ranked ARP values

ARP value ranked starting from highest value to lowest value. The result is shown in Table 6.

Table 6. Ranked ARP.

RA Code	ARP Value	RA Code	ARP Value
A14	77.76	**A15**	22.08
A11	75.46	**A18**	19.95
A3	65.57	**A2**	19.90
A5	63.91	**A4**	19.37
A10	63.70	**A17**	9.39
A6	62.25	**A16**	7.68
A7	58.10	**A13**	7.28
A1	25.11	**A8**	7.10
A12	23.96	**A19**	5.92
A9	22.69		

3.2.7. Identifying critical risk agents

Pareto chart use to identify risk agent critical category. The chart can be seen in Fig. 1. Figure 1 describe risk agents which include the critical category. Risk agent critical category is risk agent having a cumulative percentage of ARP value □ 80%. The risk agents are a limited crew competence (A14), is the one with the highest ARP score. Other major risk causes are unaccountability of crew recruitment process (A11), not well functioning of navigation equipment (A3), uncalibrated radar (A5), undisciplined crew competency certificate check (A10), incomplete navigation equipment (A6) and irregular check on navigation and safety equipment (A7), inaccurate information on cargo quantity (A1), and weather is bad (A12).

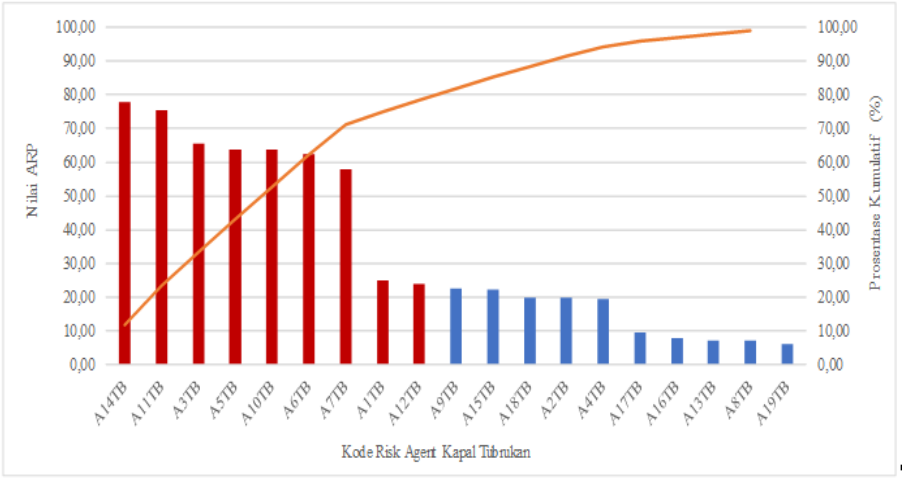

Fig. 1. Chart of risk agent and cumulative percentage each risk agent.

After obtaining risk agents critical category, then make a classification according to the type of problem. The ship is manned by the crew has limited competency caused by unaccountability of crew recruitment process, and Harbour master undisciplined in checking crew competency certificate. Uncalibrated radar, not well functioning of navigation equipment, incomplete navigation equipment, and irregular check on navigation and safety equipment due shipping company does not implement ship maintenance plans. During the application process for Port Clearance, the Harbour master only carries out an administrative check, Harbour master do not inspection to the ship, it has an impact the voyage in damaged navigation equipment condition, and inaccurate information on cargo quantity. Based on classification of risk agent critical category obtained the root cause of ship collision is crew recruitment process is not accountable, Shipping company does not implement appropriate maintenance plan, and clearance out letter approved without inspection to the ship.

3.3. House of Risk Phase 2

House of Risk Phase 2 is a step for preventive action. The preventive action shows in Table 7.

Table 7. Identification of preventive action.

Root Cause of ship collisions	Preventive action code	Preventive action
Crew recruitment process is not accountable	1PA	Create a system to ensure shipping companies carry out the selection process in crew recruitment.
	2PA	Create a system to ensure shipping companies conduct competency tests on crew recruitment
	3PA	Using technology in the crew selection process
Shipping company does not implement appropriate maintenance plan	4PA	Create a system to ensure shipping companies carry out ship maintenance plans.
	5PA	Create a system to ensure ship maintenance, and ship survey make correctly.
	6PA	Give penalties to shipping companies that do not carry out ship maintenance.
Clearance out letter approved without inspection to the ship (checking the ship stability, navigation equipment, safety equipment, and firefighting)	7PA	Create a system so that the crew can provide reports to the harbour master when they find deficiencies or damage the ship equipment, especially for items classified as critical equipment.
	8PA	Create a system to ensure the ship crew have appropriate competence.
Clearance out letter approved without inspection to the ship (checking the	9PA	Create a system and use technology in assessing sea-worthy.
Ship stability, navigation equipment, safety equipment, and firefighting)	10PA	Create systems and use technology to ensure shipping companies provide up-to-date information about the ship's condition.

From Table 7, there are ten preventive actions from three root cause of ship collisions. The crew recruitment process is not accountable has three preventive action, namely 1PA, 2PA, and 3PA. Shipping company does not implement appropriate maintenance plan has three preventive action, namely 4PA, 5PA, and 6PA. Clearance out letter approved without inspection to the ship has four preventive action, namely 7PA, 8PA, 9PA, and 10PA.

3.3.1. Assessment of relationship between classification of root cause of ship collision and preventive action (E_{jk}).

Assessment of the relationship between root cause of ship collisions and preventive action through interviews and questionnaires with respondents. The assessment results can be seen in Table 8.

Table 8. The assessment result of the relationship.

Classification of risk agent critical category	Preventive action code	E_{jk}
Crew recruitment process is not accountable.	1PA	4.79
	2PA	4.95
	3PA	5.42
Shipping company does not implement	4PA	5.42
appropriate maintenance plan.	5PA	6.88
	6PA	4.79
Clearance out letter is approved without inspection to the ship (checking the ship stability, navigation equipment, safety equipment, firefighting, and the crew competence).	7PA	7.00
	8PA	5.95
	9PA	6.47
	10PA	5.63

From the assessment (as shown in Table 8), the highest relationship value is 7.0. The preventive action has the highest value is to create a system so that the crew can report to the harbour master when the crew finds deficiencies or damage to the ship and equipment, especially for items classified as critical equipment. The value indicated the preventive action have strong relationship to the root cause of ship collision.

3.3.2. Assessment level of difficulty (D_k)

Assessment of the level of difficulty to implement preventive actions provide by 17 respondents. The assessment results can be seen in Table 9.

Table 9. The assessment result of the level of difficulty to implement preventive action.

Classification of risk agent critical category	Preventive action code	D_k value
Crew recruitment process is not accountable.	1PA	3.47
	2PA	3.58
	3PA	3.58
Shipping company does not implement appropriate maintenance plan.	4PA	3.95
	5PA	3.89
	6PA	3.79
Clearance out letter is approved without inspection to the ship (checking the ship stability, navigation equipment, safety equipment, firefighting, and the crew competence).	7PA	4.37
	8PA	3.74
	9PA	4.11
	10PA	4.11

The value of the level of difficulty to implement preventive action in between 3.47 to 4.37. It means the preventive action easy to implement.

3.3.3. Calculation of Effectiveness to Difficulty Ratio

Effectiveness to Difficulty Ratio (ETD) is a value that represents preventive actions that is classified as effective in overcoming critical risks. Before calculating ETD, we should calculate the value of Total Effectiveness (TE_k) use Eq. (3). The results of the calculation of TE_k can be seen in Table 10.

Table 10. The total effectiveness of preventive action.

Preventive action code	$\sum ARP$	E_{jk}	TE_k
1PA	75.46	4.79	361.41
2PA	75.46	4.95	373.33
3PA	75.46	5.42	409.07
4PA	13.61	5.42	73.80
5PA	13.61	6.88	90.99
6PA	13.61	4.79	65.20
7PA	46.67	7.00	326.71
8PA	46.67	5.95	277.58
9PA	46.67	6.47	302.15
10PA	46.67	5.63	262.84

Table 10 shown, the preventive action with the highest total effectiveness is 3PA. This is a solution to prevent the crew recruitment process is not accountable. The next step is to calculate the Effectiveness of the Difficulty Ratio (ETD) use formula 2. The calculation results can be seen in Table 11.

Table 11. ETD ratio.

Preventive action code	TE_k	D_k	ETD_k Ratio
1PA	361.41	3.47	104.04
2PA	373.33	3.58	104.31
3PA	409.07	3.58	114.30
4PA	73.80	3.95	18.70
5PA	90.99	3.89	23.36
6PA	65.20	3.79	17.21
7PA	326.71	4.37	74.79
8PA	277.58	3.74	74.28
9PA	302.15	4.11	73.60
10PA	262.84	4.11	64.03

From the calculation of ETD ratio (shown in Table 11), the highest value is 104.31 and the lowest value is 17.21. The highest value of ETD calculation is 2PA, and the lowest value is 6PA. The preventive action with the highest ETD ratio was identified as the most effective to prevent the root cause of ship collisions.sa

3.3.4. Evaluation the most effective preventive action

For the evaluation, the most effective preventive actions start from the highest ETD ratio to lowest ETD ratio, then making a pareto chart (shown in Fig. 2).

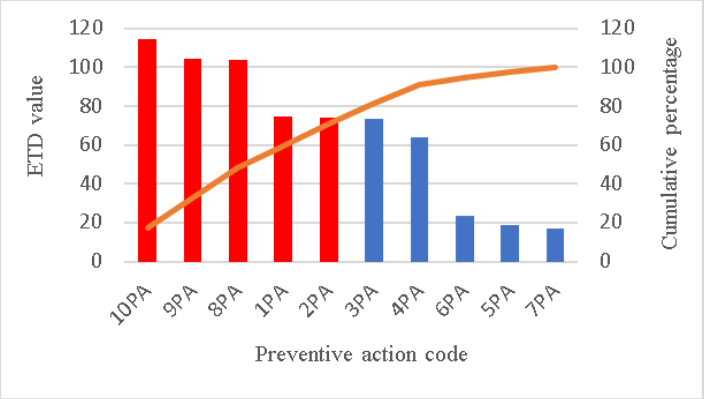

Fig. 2. Pareto chart of preventive action.

From pareto chart shown in Fig 2, the most effective preventive action has a cumulative percentage of ≤ 80%. The preventive action are create a system and using technology to ensure shipping companies provide up-to-date information about the ship's condition (10PA), create a system and use technology in assessing sea-worthy requirements (9PA), create a system to ensure the crew on board have appropriate competence (8PA), create a system to ensure shipping companies carry out the selection process in crew recruitment (1PA), and create a system to ensure shipping companies conduct competency tests on crew recruitment (2PA).

The root cause of ship collision in this study is indirect causes that sorted based on level of potential risk. Contras to the other study that identified the cause of ship collisions on direct cause. The other studies have mostly identified the cause of ship collisions due to human error, technical condition, bad weather, poor implementation of regulations and operations of ships, fires due to dangerous loads, overload, and shifting loads. The direct cause is not the root cause of ship collisions. Inaccurate in identifying causes of ship collisions will impact on preventive action ineffective, and ship collisions continue to occur. The result of this study is the root cause of ship collisions is a system problem, so that preventive action carried oud through a system approach. Regulation requires the level of ship crew competency certificate have to appropriate with Gross Tonnage of the ship manned, ship maintenance have to carried out regularly, and the ship have to in seaworthy condition before clearance out approval. This study identified the regulations were not implemented properly so that the ship collisions occur. Preventive action in this study will support the implementation of regulation carried out properly in shipping industry.

4. Conclusions

The House of Risk has successfully revealed deeper factors which might cause ship accident and the preventive action to prevent ship accidents. Having this at hand, the availability of both risk agents and risk events, a translation into a list of actions or policies is enabled. A careful identification of risk agents and risk events is a pre-requisite for delivering a correct result. The root cause of ship collision is crew recruitment process is not accountable, shipping company does not implement appropriate maintenance plan, and clearance out letter approved without inspection to the ship. The cause of the ship collision occurred during the crew preparation stage and the sailing preparation stage. Therefore, preventive action should apply at this stage. The ship collision caused by a combination of several interrelated causal factors, so that to minimize the risk of ship collision have to take a systems approach. To reduce of ship collision should be to create a system in the crew recruitment procedure at the crew preparation stage and create a system in the clearance out procedure at the sailing preparation stage.

Nomenclatures

ARP_j	Aggregate Risk Potentials
D_k	Level of difficulty to implement preventive action
E_{jk}	Evaluation of the relationship between root causes and preventive action
ETD_k	Eeffectiveness to difficulty ratio
O_j	Occurrence of the risk agent
R_i	Relationship between a risk event and a risk agent
S_i	Severity of the risk event
TE_k	Total effectiveness of preventive action
TE_k	Total effectiveness of preventive action

Abbreviations

COLREG	Collision Regulation
HOR	House of Risk
JESTEC	Journal of Engineering Science and Technology
NTSC	National Transportation Safety Committee

References

1. Kececi, T.; and Arslan, O. (2017). SHARE Technique: A novel approach to root cause analysis of ship accidents. *Safety Science*, 96, 1-21.
2. Haapasaari, P.; Helle, I.; Lehikoinen, A.; Lappalainen, J.; and Kuikka, S. (2015). A proactive approach for maritime safety policy making for the Gulf of Finland: Seeking best practice. *Marine Policy*, 60, 107-118.
3. Hu, S.; and Zhang, J. (2012). Risk assessment of marine traffic safety at coastal water area. *International Symposium on Safety Science and Technology, Procedia Engineering*, 45, 31-37.
4. Jeon, J.W.; Wang, Y.; Yeo, G.T. (2016). Ship safety policy recommendations for Korea: Application of system dynamics. *Asian Journal of Shipping and Logistics*, 32(2), 73–79.
5. Kum, S.; and Sahin, B. (2015). A root cause analysis for Arctic marine accidents from 1993 to 2011. *Safety Science*, 74, 206-220.
6. Weng, J.; and Yang, D. (2015). Investigation of shipping accident injury severity and mortality. *Accident Analysis and Prevention*, 76, 92-101.
7. Cauvin, C.; Lardjane, S.; Morel, G.; Closterman, J.P.; and Langard, B. (2013). Human and organizational sectors in maritime accidents: Analysis of accidents at sea using HFACS. *Accident Analysis and Prevention*, 59, 26-37.
8. Sotrialis, P.; Ventikos, N.P.; Hamann, R.; Golyshev, P.; and Teixeira, A.P. (2016). Incorporation of human factors into ship collision risk models focusing on human centred design aspects. *Reliability Engineering and System Safety*, 156, 210-227.
9. Yıldırım, U.; Başar, E.; and Uğurlu, O. (2017). Assessment of collisions and grounding accidents with human factors analysis and classification system (HFACS) and statistical methods. *Safety Science*, 119, 412-425.
10. Hyungju, K.; Setin, H.; and Bouwer, U.I. (2016). Assessment of accident theories for major accidents focusing on the MV SEWOL disaster: Similarities, differences, and discussion for a combined approach. *Safety Science*, 82, 410-420.
11. Graziano, A.; Teixeira, A.P.; and Soares, C.G. (2016). Classification of human errors in grounding and collisions accidents using the TRACEr taxonomy. *Safety Science*, 86, 245-257.
12. Chen, J.; Zhang, F.; Yang, C.; Zhang, C.; and Luo, L. (2017). Factor and trend analysis of total-loss marine casualty using a fuzzy matter element method. *International Journal of Disaster Risk Reduction*, 24, 383-390.
13. Pujawan, I.N.; and Geraldin, L.H. (2009). House of risk: A model for proactive supply chain risk management. *Business Proses Management*, 15(6), 953-967.
14. Agung, I.G.N. (2006). *Statistika penerapan model rerata-sel multivariat dan model ekonometri dengan SPSS*. Jakarta: Yayasan SAD Satria.