FORMAL SAFETY ASSESSMENT OF A FISHING VESSEL

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ABSTRACT

As the members of maritime industry awareness and sensitivity to the safety increase, more attention has been directed to ship safety. More people demand control over risk to which they are exposed and to model the uncertainties of risk and to seek measures of reduction. Therefore, this reality results in high cost in safety and money. The main purpose of the paper is to review the process of Formal Safety Assessment and to propose for a generic fishing vessel. In this circumference, a trial application of a formal safety analysis was attempted. An interactive risk table method is presented to produce an overall ranking for further attention in fishing vessel design and operation. Furthermore, a sample fault tree analysis is applied to find the relative importance of each component. Finally, some suggestions are made to reduce the risks and emphasized that more failure data needs to be collected on an industry basis and that much expert judgement from a qualitative point of view is required in order to control risks.

Keywords: Fishing Vessel, Fishing Vessel Safety, Safety Assessment, Fault Tree

1. Introduction

The members of maritime industry are aware of and sensitive to the safety and, more attention has been directed to ship safety. Therefore, more people demand control over risk to which they are exposed and to model the uncertainties of risk and to seek measures of reduction. Thus, the benefits of technology results in high cost taking into account the safety.

The offshore industry moved to a new era in risk assessment soon after the tragical accident of the “Piper Alpha”. Piper Alpha was an oil and gas platform 110 miles from Coast of Aberdeen in the North Sea that was built in 1976. On July 6, 1988 a gas processor had exploded and set of a chain reaction which led to massive explosions that completely destroyed the platform in three hours. The disaster caused 167 deaths out of the 228 working on board at that time. The inquiry to investigate the causes of the disaster led to the largest safety reform in offshore industry. Thus, “The Offshore Installation Regulations” issued by the UK Health and Safety Exucutive (HSE, 2001) come into force in 1993. The regulations required operational safety cases to be prepared for all existing offshore installations till November 1993 and both operational and design safety cases for new installations.

In the maritime industry, the International Maritime Organization (IMO) implements the principles of risk management and a systematic process called Formal Safety Assessment (FSA). FSA was introduced as a process to assess risks and to evaluate costs and benefits of the IMO’s options for reducing these risks and, then, to provide support to the organization’s decision making process. FSA was proposed by the UK and based on the risk assessment approach of the country’s offshore industry. The IMO, initially in 1993, studied FSA at the 62nd meeting of MSC (marine and safety committee) following a proposal by the UK’s Marine

Coastquard Agency (MCA). Two years later, in 1995, MSC 65 agreed that FSA should be a high priority on its agenda and in 1997 MSC at its 68th session and the Marine Environment Protection Committee (MPEC) at its 40th session approved the "Interim guidelines for the application of Formal Safety Assessment to the IMO rule making process". Experience from the trial applications since 1997 the guidelines (MSC Circ. 1023) that were adopted at MSC 74 and MPEC 47, superseded the interim guidelines. The new guidelines are called "Guidelines for Formal Safety Assessment for use in the IMO rule making process" (MSC Circ. 1023 and MPEC Circ. 392, 5 April 2002).

In 2002 the International Maritime Organization (IMO) approved guidelines for the Formal Safety Assessment (FSA) as "a rational and systematic process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks"(IMO, 2002; MSC-MEPC.2/Circ.12, LONDON, UK; 2013). The basic philosophy of the FSA is that it can be used as a tool to facilitate a transparent decision-making process. In addition, it provides a mean of being proactive, enabling potential hazards to be considered before a serious accident occurs. However, the description of the method can give an impression that the definition of the word "risk" does not fully reflect the way the risk is further explained and it seems that the components relevant for risk description change depending on the context. In the context of risk analysis, presented in the FSA guidelines risk is defined as a combination of the probability (P) and consequences (C) of a given action (IMO; Aug, 2012). Further in the guidelines, in Chapter 7 "Risk control options", the risk is decomposed and the uncertainty aspect of two risk components (P, C) is added as an important element of the decision process. Moreover, for the identification of risk control measures, Sub-chapter 7.2.2 suggests developing causal chains of events leading to an accident, which means that the definition of risk includes an insight into certain scenarios leading to the undesired situations. Finally, Chapter 10, "Presentation of FSA results", stresses the need for a discussion about the assumptions, limitations and uncertainties of a risk model. It has been argued that the FSA, presented as a proactive, highly technical and complex method, can be misused, yielding results which may not fully reflect the relevant features of the analyzed system (Devanney, 2013; Kontovas,2009).

The IMO organized an international conference which culminated in the Torremolinos International Convention for the safety of fishing vessels, in order to recognize the need for attention to safety of commercial fishing vessels in 1977. It established uniform principles and rules regarding design, construction and equipment for fishing vessels 24 m in length and over. It was adopted at the Torremolinos Protocol of 1993 relating to the Torremolinos International Convention for the Safety of Fishing Vessel, 1977. The IMO convention on standart of training, certification and watch keeping for seafarers (STCW) 1978 is another important factor. Notable among these efforts is the Document for Guidance on Fishermen's Training and Certification, An International Maritime Training Guide. London (IMO, 1988) and Code of Safety for Fishermen and Fishing Vessels, Part A – Safety&Health Practices for Skippers and Crew, London (IMO, 1975a). Furthermore, Voluntary Guidelines for the Design, Construction and Equipment of Small Fishing Vessels, an International Maritime Training Guide. London(IMO, 1980) and Code of Safety for Fishermen and Fishing Vessels, Part B – Safety&Health Requirements for the Construction and Equipment of Fishing Vessels, London(IMO,1975b). These standarts are jointly prepared by IMO and two other United Nations subsidiaries, Food and Agriculture Organization (FAO) and International Labour Organization (ILO).

The overall objectives of this paper are to analyse of the most important factors affecting fishing vessels safety and to give guidance on how improvements in safety. For this purpose, a trial application of a formal safety assessment on a generic fishing vessel was carried out. The generic fishing vessel is a hypothetical vessel of any size and method of fishing. It is an appraisal of the functions of operation that is necessary for any fishing vessel.

2. Formal Safety Assessment

Risk can be defined in many ways. According to the FSA guidelines, risk is the combination of the frequency and the severity of the consequence. 'Consequences' are the unwanted events that can be negatively affect subjects of interest such as people, property, environment etc. On the other hand, 'frequency' is the number of occurrences of an undesirable event expressed as events per unit of time. Risk does not mean actual danger but the possibility of danger (HSE, 2001). The word risk must contain the concept of probability that is something probable. Finally, risk is a measure of the likelihood that an undesirable event will occur together with a measure of the resulting consequence within a specified time i.e. the combination of the frequency and the severity of the consequence (MSC 76/Inf. 3).

The problem of risk led to the development of risk related disciplines like Risk Analysis, Risk assessment and Risk Management. Risk analysis is the systematic use of available information to identify hazards and to estimate the risk to individuals or populations, property or the environment; Risk assessment is to review the acceptability of risk that has been analyzed and evaluated based on the comparison with standarts or criteria that define the risk tolerability; Risk management is the application of risk assessment with the intention to inform the decision making process with the appropriate risk reduction measures and their possible implementation (IEC, 1994).

According to the Guidelines, "FSA is a rational and systematic process for assessing the risk related to the maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing these risks. FSA's basic philosophy is that it can be used as a tool to facilitate transparent decision making process that provides a clear justification for proposed regulatory measures and allowing comparison of different option of such measures to be made'.

The Formal Safety Analysis can be developed into five steps as follows:

Step 1: Identification of hazards,
Step 2: Assessment of the risks,
Step 3: Risk control options or risk ranking,
Step 4: Cost benefit assessment of the risk management,
Step 5: Recommendations for decision-making between options available.

Fig. 1 shows that how each step of the FSA is interrelated with each other.

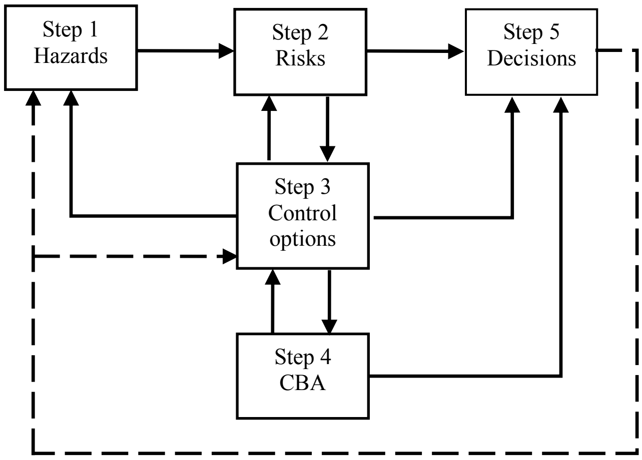

Fig 1. Flowchart of the FSA process.

3. Formal Safety Analysis of a generic fishing vessel

In this study, formal safety analysis proposed addresses the high risk areas which need design and /or operational attention. The generic fishing vessel (hypothetical vessel) is a vessel of any method of fishing. Fishing is cyclic with the following phases of life:

- Design and construction,
- Commisioning,
- Berthing, unberthing, entering port and leaving port,
- Fish loading and unloading,
- Dry dock and maintenance period,
- Decommisioning and scrapping.

The status of the ship's function changes in the phases of life. The factors that will affect the safety and reliability of the vessel are as follows:

- Human,
- Communications,
- Emergency, response / control,
- Machinery, power /propulsion,
- Management system,
- Navigation,
- Piping and pumping,
- Mooring / towing, anchoring, lifting,
- Electrical systems,
- Structure and payload,
- Bunkering / storing,
- Stability, manoeuvrability,
- Pollution prevention,
- Habitable environment.

According to the flowchart of the FSA process, a test case study on a generic vessel can be defined in Fig. 2.

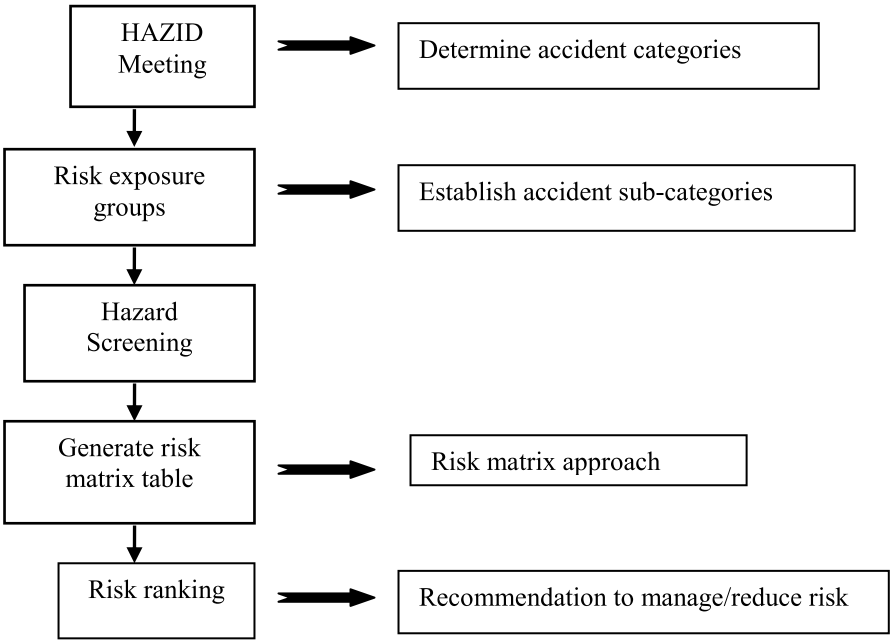

Fig. 2. Flowchart of the proposed approach

The first step of the proposed analysis is the hazard identification (HAZID). This consists of determining which hazards affect the fishing vessels' activities using 'brainstorming' techniques. Trained and experienced personnel are required to systematically identify all potential failure events with their influences on system safety and performance. Information produced from the hazard identification phase will be processed to estimate risk.

Various safety analysis methods include:

a) Preliminary hazard analysis (Henley and Kumamoto, 1992; Smith, 1992; Villemeur, 1992)
b) Fault tree analysis(Henley and Kumamoto, 1992; Smith, 1992; Villemeur, 1992; Köse, 1998)
c) Event tree analysis(Henley and Kumamoto, 1992; Smith, 1992; Villemeur, 1992;Köse, 1998)
d) Cause-consequence analysis(Henley and Kumamoto, 1992; Smith, 1992; Villemeur, 1992)
e) Hazard and operability analysis(Henley and Kumamoto, 1992; Villemeur, 1992)
f) Boolean representation method(Wang et al., 1995)
g) Simulation analysis(Henley and Kumamoto, 1992; Villemeur, 1992)

Accident categories that are considered in this study include:

- Flooding,
- Foundering,
- Grounding,

- Collision,
- Fires and explosions,
- Heavy weather damage,

Having identified the accident categories, the causes are then grouped into following risk exposure groups (Loughran et al. 1995):

1. Human errors
   - Human performance, manning,
   - Communication,
   - Onboard management,
   - Navigation,
   - Loading and unloading fish,
   - Catching,
   - Anchoring / mooring,

2. Hardware failures
   - Refrigeration,
   - Structure,
   - Safety systems,
   - Electrical systems,
   - Propulsion,
   - Habitable environment,
   - Steering,
   - Piping / plumbing,
   - Bunkering / storage,

3. External events
   - Environment,
   - Payload,
   - Climatic variations,
   - Berthing, unberthing, entering port and leaving port.

In order to sort the large amount of information collected at the HAZID meeting, a set of accident sub-categories can be established as follows (Loughran et al. 1995):

1. Collision and contact accident subcategories
   - Berthing,
   - Starting up,
   - Loading and unloading in port,
   - Manoeuvring close to the berth,
   - Passage in open sea,
   - Loading fish at sea,
   - Entering harbor,
   - Shutdown,
   - Abnormal operation,
   - Maintenance,

- Anchoring,
- Dry-docking.

2. Fire accident subcategories
- Engine room,
- Fish room space,
- Wheelhouse,
- Accomodation,
- Galley.

3. Loss of hull integrity accident subcategories
- Hull plating,
- Framing,
- Bulkheads,
- Welds and joints,
- Openings or failure of doors,

4. Risk Matrix Approach

Risk matrices provide a traceable framework of the frequency and consequences of hazards. A risk matrix uses a matrix dividing the dimensions of frequency and consequence into categories. Each hazard is allocated to a frequency and consequence category and then it gives a form of evaluation or ranking of the risk. Therefore, the risk matrix is the most important tool that is provided to the group of experts and is used in the hazard screening process. For each appropriate combination, an assessment has been made of the frequency (F) of the accident and the severity (S) of the consequences in terms of human injuries / deaths, property damage / loss and the degradation of the environment. The corresponding risk ranking number (RRN) is then selected from the risk matrix table.

In the maritime industry, IMO has introduced a 7×4 risk matrix. To facilitate the ranking, it is generally recommended to define consequences and probability indices on a logarithmic scale. A risk index may therefore be established by adding the probability / frequency and consequence indices.

$$\text{Risk} = \text{Probability x Consequences}$$
$$\text{Log(Risk)} = \text{Log(Probability) x Log(Consequences)}$$
$$\text{Risk Index} = \text{Frequency Index} + \text{Severity Index}$$

The risk matrix can now be constructed as follows (MSC Circ. 1023):

Table 1. Risk Index

RISK INDEX (RI)					
FI	**FREQUENCY**	**SEVERITY (SI)**			
		1	**2**	**3**	**4**
		Minor	**Significant**	**Severe**	**Catastrophic**
1	Extremely remote to extremely improbable	2	3	4	5
2	Remote to extremely remote	3	4	5	6
3	Remote	4	5	6	7
4	Reasonably probable to remote	5	6	7	8
5	Reasonably probable	6	7	8	9
6	Reasonably probable to frequent	7	8	9	10
7	Frequent	8	9	10	11

Table 1 gives a risk level related to the frequency and severity of an accident. RRN ranges from 2 (least frequent and least severe consequence) to 11 (most frequent and most severe consequence).

5. An Example

Estimated characteristics of a generic fishing vessel are as follows:

- Vessel life expectancy: 20 years
- Operational days per year: 200
- Operational hours per day: 12
- Major maintenance per year: 1

Risk matrix table according to IMO:

Table 2. Severity Index (MSC Circ. 1023).

SEVERITY INDEX (SI)				
SI	Severity	Effects on Human Safety	Effects on ship	S (Equivalent fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries.	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

Table 3. Risk matrix table of a generic fishing vessel

		F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
S1	Minor injuries	1	2	3	4	5	6	7
S2	Major injuries	2	3	4	5	6	7	8
S3	1–10 deaths	3	4	5	6	7	8	9
S4	>10 deaths	4	5	6	7	8	9	10

In this table, S1 (Minor injuries) refers to less than minor injury, occupational illness or system damage; S2 (Major injuries) refers to minor injury, minor occupational illness or minor system damage; S3 (1–10 deaths) refers to severe injury, severe occupational illness or severe system damage and S4 (>10 deaths) refers to death or system loss.

Risk ranking can be generated by analyzing the incident / accident data in terms of its recurrence and severity of consequences from the MAIB (the Marine Accident Investigation Branch, 2008). Table 4 represents an example for collision and contact accident category. Each accident category can be analysed and handled in a similar method to produce a ranking number for each accident subcategory.

Table 4. Collision and contact ranking

Accident Subcategory	Berthing / Unberthing	Entering / leaving port	Fish handling, Coastal	Fish handling, Open sea	Dry dock, Maintenance
Starting up	F4S1 = 4	F4S1 = 4	F4S1 = 4	F3S1 = 3	F4S1 = 4
Manoeuvring	F5S2 = 6	F6S2 = 7	F6S3 = 8	F6S3 = 8	F4S1 = 4
Shutdown	F4S2 = 5	F4S1 = 4	F5S3 = 7	F5S3 = 7	F4S1 = 4
Abnormal operation	F3S1 = 3	F5S2 = 6	F6S3 = 8	F6S3 = 8	F3S1 = 3
Anchoring	F5S1 = 5	F3S1 = 3	F3S1 = 3	F2S1 = 2	F2S1 = 2

Having identified the high-risk areas and ranking them in order of importance, the next step would be to make recommendations to manage / minimize the risk for the associated hazards. This could be achieved by the 'brainstorming' method. The decision would be dependent on several factors such as cost, availability and effectiveness. The formal safety analysis can be further developed to make it more elaborate and complete by using the MCA or IMO type of formal safety assessment for a generic vessel.

5.1 Fault Tree Analysis

The availability of data and quality of information will affect the degree of uncertainty. However, provided that reliabilty models are based on rational principles, the lack of data might not lessen too much the usefulness of the model. Since fault tree approach provides a systematic procedure for identifying faults, it has found a growing use in many engineering fields. On the other hands, fault tree analysis has disadvantages and advantages as follows:

Disadvantages:

- The first major disadvantage is oversight and omission.
- The second one is the binary assumption for the component state, i.e. failure or success.
- The third one is related to the assumption that all basic events are considered non-repairable.

Advantages:

- The first major advantage is the capability of displaying the relative importance of each component.
- Secondly, minimal cut sets are used to identify the weakest points of the system.
- The third one is that the importance levels can be found to rank each component.

Fault Tree Analysis is a logic diagram showing the causal relationship between events. It is used to determine the probability of a top event which may be a type of accident or unintended hazardous outcome. Fault trees can include failure events or causes related to human. Therefore, they are useful for undestanding logically how an accident occurred and the probability of a top event can be calculated taking into account the failure probabilities of system components.

The development of a fault tree is by a top-down approach considering the causes or events at levels below the top level systematically. To carry out an analysis, a description of how the output states of each component are influenced by the input states and of how the components are interconnected. Therefore, a functional layout diagram of the system must show all functional interconnections.

If two or more lower events cause the next higher event, this is shown by a logic .and. gate. If any one of two or more lower events causes the next higher event, this is shown by a logic .or. gate. The logic gates determine the addition or multiplication of probabilities (assuming independence) to obtain the values for the top event (IMO Circ. 1023). Construction, usually, starts with the top event which would normally be the major hazard such as ship loss, and works down towards the basic events. The event symbols are rectangle, circle, diamond and triangle. The rectangle resresents a fault output event which results from a combination of basic faults and/or intermediate events acting through the logic gates. The circle is used to designate a primary or basic fault event. The diamond describes fault inputs that are not basic events but considered basic fault input since the cause of the fault has not been further developed due to lack of information. The triangle is not strictly an event symbol but is traditionally classified as such to indicate a transfer from one part of a fault tree to another.

The fault tree does not offer an exact solution to the problem. The main purposes of this approach are to provide the systematically derived information that makes a rational decision and to design safe fishing vessels.

As a preliminary model of the fault tree shown in Fig. 3 considering the accident category ‘collision’. The fault tree analysis for a fishing vessel is given in details as an example in Köse, E. at al (1998).

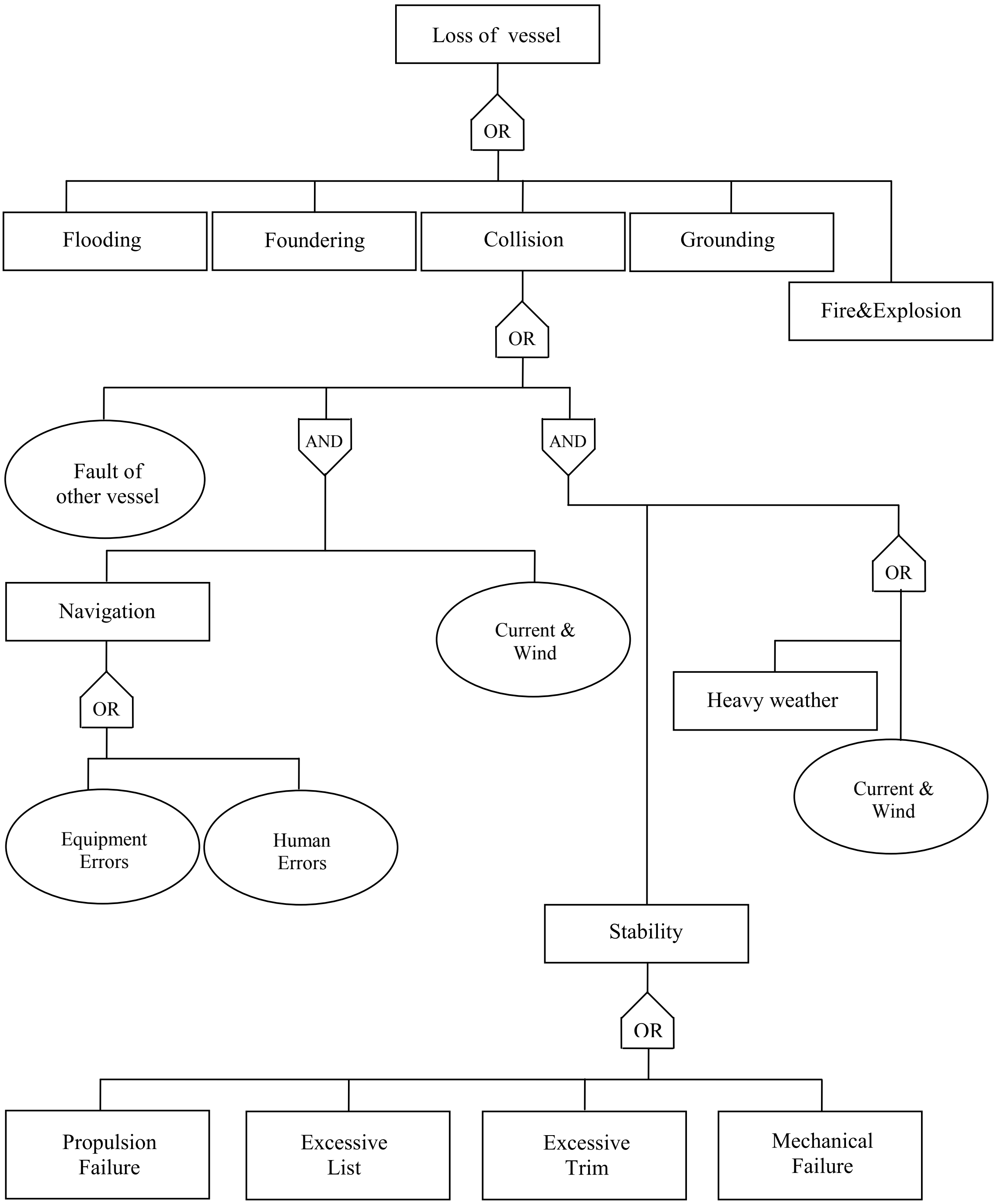

Fig. 3a An example of the evaluation of the fault tree.

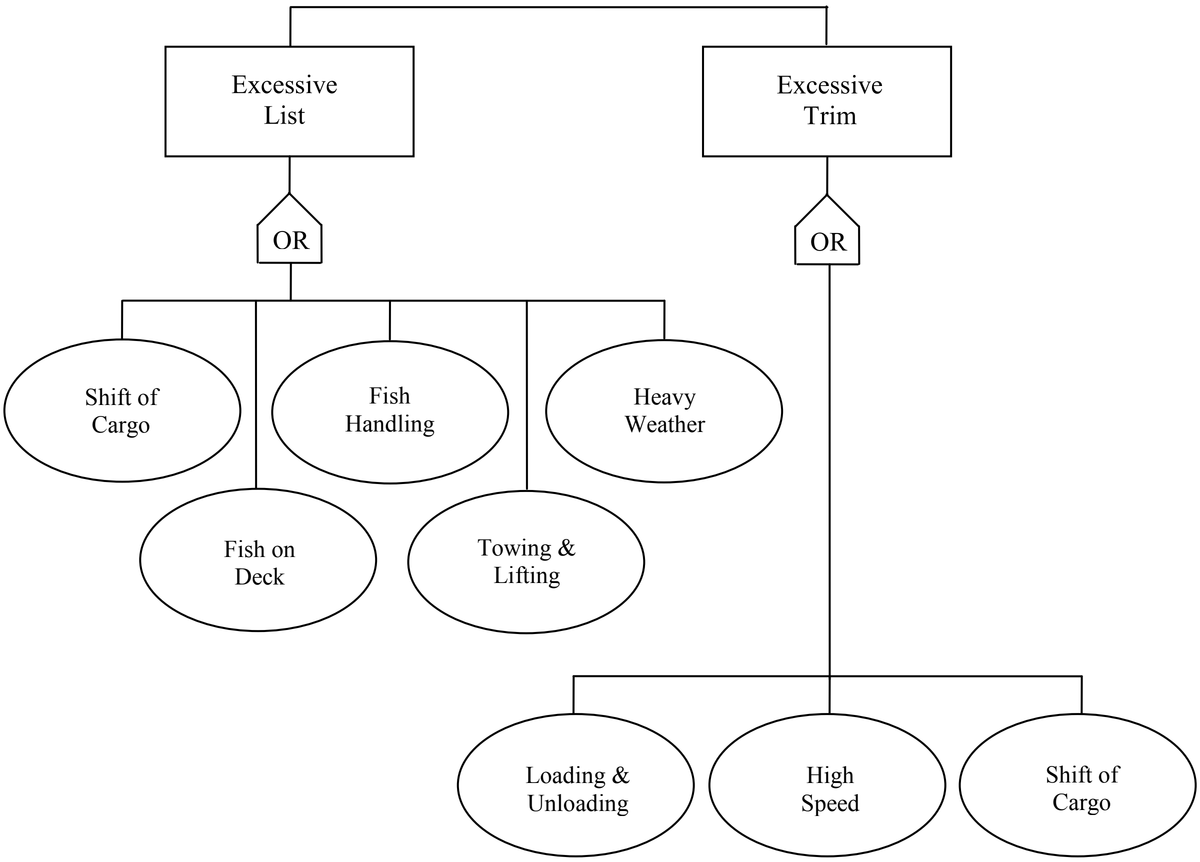

Fig. 3b An example of the evaluation of the fault tree (continued).

6. Conclusions

Human errors are one of the most common types of error. Therefore, it is of great importance to reduce the human errors that will affect the safety and reliability of the vessel. Some factors can contribute to human errors mainly such as exposure to high level of noise and vibration or stress due to fishing. These contributions can cause the major human errors as follows:

- Misjudge effects (wave, wind, current, speed)
- Crew inattention
- Failure to ascertain position
- Watchkeeper incapacitated on bridge
- Failure to utilize available navigation equipment

In this circumference, we have solutions of an educational and organizational based to reduce human errors. It is obvious that training becomes very important for safety. This would require a compulsory course related to the human functions such as knowledge of regulations and use of equipment. Fault tree analysis can be used as a training aid and a tool for increasing awareness. On the other hand, in order to reduce human errors, vibration and noise should be minimised because of their significant effects.

The main and the auxiliary power systems in the small spaces on fishing vessel will lead to an increasing number of complaints by crews considering the noise, the mechanical vibrations and its effects on their health, stress levels, concentration and safety.

Furthermore, it is possible to reduce the probability of collision by installing a radar, collision detector and redesign of the bridge equipment. The fishing industry is an outstanding target group for extension of the use of this sort of instrument, but it will need to be reduced in cost.

The proposed analysis does not address whole fishing vessel safety. In this paper, a trial application of a formal safety analysis on a generic fishing vessel was attempted. At present much expert judgement and evidential reasoning from a qualitative point of view is required. The data required for quantitative assessment is either unavailable or far from the ideal format. This could be attributed to the organizational structure of the fishing company and/or the reporting requirement of accidents and incidents.

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