Tr. J. of Engineering and Environmental Science
22 (1998) , 417 – 428.

Risk Assessment of Fishing Vessels

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Received 01.07.1997

Abstract

The work described in this paper is concerned with the systematic analysis of the hazards of fishing vessels. Statistical data is reviewed and analysed and fault tree analysis is applied to find the relative importance of each component with respect to system reliability. In this analysis, the loss of vessel is chosen as the top event, then branching out to the basic events such as human error, structural failure, fish on deck etc. This method is considered an essential approach for providing a much better basis for safety decision making.

Finally, in order to reduce the accidents to vessels and crew, some suggestions are made to reduce the probability of human error to improve the stability and safety of vessels.

Key Words: Fishing Vessels, Risk Assessment, Fault Tree, Human Error

Balıkçı Gemileri, Risk Analizi, Hata Ağacı, İnsan Hatası

Özet

Bu çalışmada, balıkçı gemileri kazalarının sistematik analizleri açıklanmaktadır. Bu bağlamda, istatistiki veriler incelenerek Hata Ağacı (Fault Tree) yöntemi, her bir etkenin önemini belirlemede kullanıldı. Bu analizde, geminin batışbaş (son) olay olarak seçildi ve insan hatası, yapısal hata ve güverteye balık koyma gibi temel etkenlere dallandırıldı. Bu yöntem literatürde, emniyet için karar vermede sağlıklı bir yaklaşım olarak tanımlanmaktadır.

Sonuç olarak, gemilerdeki insanlara ve gemiye vereceği zararı azaltmak için, insan hatasını ve yapısal hataların nasıl aza indirilebileceği yönünde önerilerde bulunulmuştur.

Anahtar Sözcükler: Balıkçı Gemileri, Risk Analizi, Hata Ağacı, İnsan Hatası

Introduction

No engineering problem can be isolated from the question of safety since no human endeavour can be free of hazards or risks. It is apparent that the need for safety measures will be influenced by the existence of such hazards or risks. In this respect, fishing vessels are no exception. Every engineer engaged in marine activities could, to some extent, involve himself in the development of methods aimed at providing maximum marine safety.

Fishing is a difficult and hazardous occupation, a fact that no one can deny today. It is an occupation that taxes both body and soul.

In general, the term safety implies that no accident is acceptable but this is in contrast to the maritime field where the reality is that a substantial risk of accident is always present.

Accident prevention may be considered at three stages

- Design stage
- Construction stage
- Operation stage

All the design stage, it is important to check whether any safety regulation has been violated or no, and determine what kind of recommendations are provided by the rules of classification societies. It is also necessary to design an adequate protective system to withstand the effects of accidents. Thus, every possible means of eliminating hazards can be taken into proper consideration.

The next stage is the construction stage. Its function is mostly related to the suprevision of whethe those safety features considered in the design stage were properly constructed and provided.

At the operation stage, the quality of crews and a good maintenance policy will influence safety, in particular the avoidance of hazards.

Review of Previous Work

To understand the current state of marine safety and make a positive move forward for the promotion of marine safety, a brief review of the historical and technical aspects of fishing vessel safety is presented in this section.

The recommendations of the committee of Enquiry were adopted by the U.K. Government and legistlation followed which resulted in the Fishing Vessels (Safety Provisions). Act 1970 and ultimately the Fishing Vessels (Safety Provisions) Rules 1975. These rules cover most ascepts of fishing vessel safety and include requirements for freeboard, stability, fire protection and watertight integrity. Although the recommendations of the Holland-Martin Enquiry were directed primarily to vessels of 24.4 metres in length and above, the 1975 rules require mandator surveys of fishing vessels 12 metres in length and above.

In 1977 at the Torremolinos Convention, guidelines for the safety of fishing vessels over 24m in length were drawn up and in 1980 by the joint IMO/FAO working group or vessels lesss than 24m.

Y.S. Yang (1989) has suggested tnaht because so many of the factors influencing the capsizing of ships are essentially probabilistic in nature, it follows that stability assessment must ultimately be based on some form of risk analysis.

Authors have explained that the assessment of the risk that a given ship, with a given set of characteristics will capsize (or reach some other unacceptable condition of stability) during its expected life, must in the end attempt to take account, in a rational and logical way, of the many varying parameters which influence that risk. And they have devised a practical scheme for the formal assessment of risk of capsize for a given ship. This might initially provide a basis for comparative assessment of ship safety against capsize and also for exploring the inflence of ship design parameters on survivability.

Accidents at sea are rarely the result of a single event, and it is likely that safety assessment must eventually be based on techniques, such as fault tree analysis, which can model the possible sequences of events or malfuctions leading to an accident (Cadwell et al. 1985).

The quantitative aspects of fault tree analysis, which is the most widely used of the system safety techniques, were investigated with Boolean algebra which provides an analytical tool for resolving and simplifying problems in fault tree logic. Perhaps because of the increasing complexity of onboard systems and growing public concern about marine accidents, marine industries and classification societies had to develop more proper appraisal methos for assessing the safety and reliability of marine systems in order to keep pace with the advances in marine technology. In this respect, several studies have been published by Lloyd's Register of Shipping (Aldwinckle andLewis, 1984). In these papers some of the theoretical methods are presented and those methods are discussed in detail and illustrated by examples, namely fault tree analysis, failure mode and effect analysis. And some approaches are given to establish criteria by which the acceptability of risk can be assessed in marine safety.

Limitation of This Study

As with any model in engineering, there are some criticisms in using statistical concepts, because of the lack of data . The availability of data and quality of information will, of course, affect the degree of uncertainty. However, provided that reliabilty models are based on rational principles, the lack of sufficient data might not lessen too much the usefulness of the model.

Unlike other techniques, fault tree analysis has also limitations due to he introduction of certain assumptions for the practical implementation of the method. The first major disadvantage is oversight and omission. There is always the possibility that some failure modes have been overlooked, even by experts. It is necessary to have a checking procedure by which the fault tree model constructed should be examined by others. Hence, it might be costly and time-consuming to apply fault tree analysis for complex systems the first time. The second problem is the binary assumption for the component state, i.e. failure or success. Therefore, fault tree analysis can not treat multistage performance, other than total failure or working. The third limitation is related to teh assumption that all basic events are considered nonrepairable, although in practice, some components might possibly be repaired before the accident occurs. As usual, the lack of pertinent failure data is also a problem. Despite these drawbacks, fault tree analysis has found a growing use in many engineering fields, since this technique provides a systematic procedure for identifying faults.

As is common in engineering practices, the techniques developed here do not offer an exact solution to the problem under consideration. In other words, the results obtained through the analysis of mathematical models are not the final answer, but rather provide systematically derived information upon which some rational decision can be made. Therefore, analytical tools that provide an insight into the problem and extend the designer's capability are developed to desing safe fishing vessels.

Objectives

Safety standards at sea should be logically based on the consideration of an adequate level of risk which includes the problem of identifying and evaluating the hazards of the seas.

Of particular interest in this study was the identification of the most important factrs affecting fishing vessel safety and to give guidance on how improvements in safety can be made.

The first objective of this study was to identify the most significant type of casualty. The common way of doing this is to investigate casualties in past decades, and analyse those data with statistical methods.

The second objective was to investigate the basic principles of the system safety engineering, primarily fault tree analysis, and its appilcation to the safety of fishign vessels. Modern vessels are charcterised by the presence of many protective devices and control systems which are considered indispensable for the safe operation of vessels. Due to the ever incerasing complexity and sophistication of onboard systems, it has gradually been acknowledged that some hazard e.g. collision, fire and exploison, were directly related to systems installed for preventing the relevant hazards.

There is a need to develop more systematic techniques to deal with the safety of marine engineering systems, and thus hopefully to improve fishing vessel safety in general. The method developed to provide a means of evaluation safety hazards of fishing vessels has a significant advantage over the conventional techniques using historical information and knowledge of the system in that it permits the quantitative investigation of fishing vessel hazards and also highlights the vulnerable areas in the systems in order of priority.

The third objective was to give guidance on how improvements in safety can be made. This study makes some suggestions on improvements to safety using the results of statistical analyses. These suggestions are related to education and desing.

Fault Tree Analysis

Fault Tree Analysis (FTA) is a logical and diagrammatic method used to evaluate the probability of an accident resulting from sequences and combinations of faults and failures. A fault tree describes an accident model which interprets the relation between malfunction of components and observed symptoms. Thus, fault trees are useful for undestanding logically how an accident occurred. Furthermore, a given the failure probabilities of system components, the probability of a top event occurring can be calculated.

Fault tree anaysis consists of the following four steps:

- System definition
- Fault tree construction
- Qualitative evaluation
- Quantitative evaluation

System Definition

Fault tree analysis begins with the statement of an undesired event, e.g. failed state of a system. To perform a meaningul analysis, the following three basic types of system information are usually needed (Chaplin and Burney, 1988).

- Component operating and failure modes: A description of how the output states of each component are influenced by the input states and internal operational modes at the component.
- System chart: A description of how the components are interconnected. A functional layout diagram of the system must show all functional interconnections and identify each component.
- System boundary conditions: These define the situation for which the fault tree is to be drawn.

Fault Tree Construction

Fault tree construction, the first step of failure analysis of a technical system, is generally a complicated an time-consuming task.

A fault tree is a logical diagram constructed by deductively developing a specific system failure, through branching intermediate fault events until a primary event is reached. Two kinds of symbol are used in faul tree construction, logic symbols and event symbols.

The logic symbols or logic gates are necessary to interconnect the events. The most frequently used logic gates in the fault tree *an* and and *or* gates. The and gate produces an output if all input events occur simulltaneously. The or gate yields an output even if one or more of the input events are present.

The event symbols used 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 throuh 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 indicte a transfer from one part of a fault tree to another.

To complete the the construction of a fault tree for a complicated system, it is necessary first to understand how the system works.

In practice, all basic events are taken to be statistically independent unless they are common cause failures. Constrction of a fault tre is very susceptible to the subjectivity of the analyst. Some analysts may perceive the logical relationships between the top event and the basic events of a system differently. Therefore, once construciton of the tree has been completed, it should be reviewed for accuracy, completeness and checked for omission and oversight. This validation process is essential to produce a more useful fault tree by which the system's weaknesses and strengths can be identified.

Qualitative Evaluation

Qualitative fault tree analysis consists of determining the minimal cut sets and common cause failures.

The qualitative analysis reduces the fault tree to a logically equivalent form, with Boolean algebra, in terms of the specific combination of basic events sufficient for the undesired top event to occur. In tis case, each combination would be a critical set for the undesired event. The relevance of these sets must be carefully weighted and major emphasis placed on those of greatest significance.

To illustrate this procedure more specifically, let us consider the following fault tree.

For evaluation of the fault tree the following procedures are necessary:

Step 1. Write gate expressions

$$Top = G1G2$$

$$\begin{aligned} &G1 = G3 + E1 \quad G2 = E3 + G4 \\ &G3 = P1E2 \quad G4 = G5 + E1 \\ &G5 = P1E4 \end{aligned}$$

Step 2. Substitute the gate expressions with the primary events upward throught the gates

$$\begin{aligned} &G3 = P1 + E2 \quad G5 = P1E4 \\ &G1 = P1E2 + E1 \quad G4 = P1E4 + E1 \\ &G2 = E3 + P1E4 + E1 \end{aligned}$$

$$Top = G1G2 = (E1 + P1E2) * (E1 + E3 + P1E4)$$

So the top event is expressed in terms of basic events P1, E1, E2, E3 and E4.

Step 3. Eliminate the redundant events with Boolean algebra

$$Top = (E1 + P1E2)(E1 + E3 + P1E4)$$

$$
\begin{aligned}
&= E1E1 + E1E3 + E1P1E4 \\
&\quad +P1E2E1 + P1E2E3 + P1E2P1E4 \\
&= E1 + E1E3 + E1P1E4 + P1E2E1 \\
&\quad +P1E2E3 + P1E2E4 \\
&= E1 + P1E2E3 + P1E2E4 \\
&= E1 + P1E2E3 + P1E2E4
\end{aligned}
$$

which states that the top event can occur by any of three critical sets.

$$(E1), (P1E2E3), (P1E2E4)$$

A more detailed explanation of this procedure is given by Köse, (1991).

Quantative evaluation

The first step in the quantitative evaluation of a fault tree is no find the structural representation of the top event in terms of basic events. Finding the minimal cut sets is one way of accomplishing this step. If the rate of occurrence for all basic events is known and the statistical dependency of each basic event is known (or assumed) then the statistical expectation or probabality of the top event can be determined. Some difficulties may arise at this stage due to lack of data. Nevertheless, quantitative evaluations are particularly valuable for comparing system designs that have similar configugrations.

The systm unavailability can then be calculated either

1. Exactly, by using the minimal cut sets/paths sets to write the structure function of the tree as the sum of the product of basic events or

2. Approximately, with one of the following standard methods (Chaplin and Burney 1988).

a) The inclusion-exclusion method of finding successive upper and lower bounds to the probabiblity of the top event in terms of the minimal cut sets.

b) The minimal cut upper bound and minimal path lwaer bound when the basic events are statistically independent.

c) The min-max bound for statisticaly dependent basicl events i.e. the basic events are associated.

Each approach has an advantage and disadvantage. The Boolean approach is the most accurate, but it takes a lot of time and space if the basic events exceed 15. However, the approximate method might give different results from the exact method.

Evaluation of a Fault Tree

As a preliminary evaluation of the fau tree shown in Figure 1 a model is developed for te loss of a vessel, the quantitative analysis is first carried out to determine the minimal cut sets with Boolean algebra on a computer to ensure error free and systematic manipulation.

For the system analysed in this case, 86 minimal cut sets were found. In other words, there are 86 different ways of reaching the top event.

More specifically, a total of 4 minimal cut sets wer identified as single order events which can lead to the top event, and 31 minimal cut sets were found to be second order failure events. The rest i.e. 51 minimal cut sets are third order failure events. Full details of the minimal cut sets are summarised with the basic event (Köse 1991)

Surprisingly, the number of cut sets is quite large, but if the working conditions of vessels are examined, the results are not a surprise at all. In fact, these cut sets may give some idea as to what is important as far as safety is concerned.

As shown by Köse (1991), the probability of the top event is mostly dependent on the probabilities of the first order minimal cut sets. The probabilities of minimal cut sets are found by using the probabilities obtained from statistics and fishermen (Chaplin, 1988). While the probability of first order minimal cut sets is 2.11×10^3, the probability of second order minimal cut sets is 1.71×10^{-6}. The probabiltiy of third order minimal cut ses is even lower.

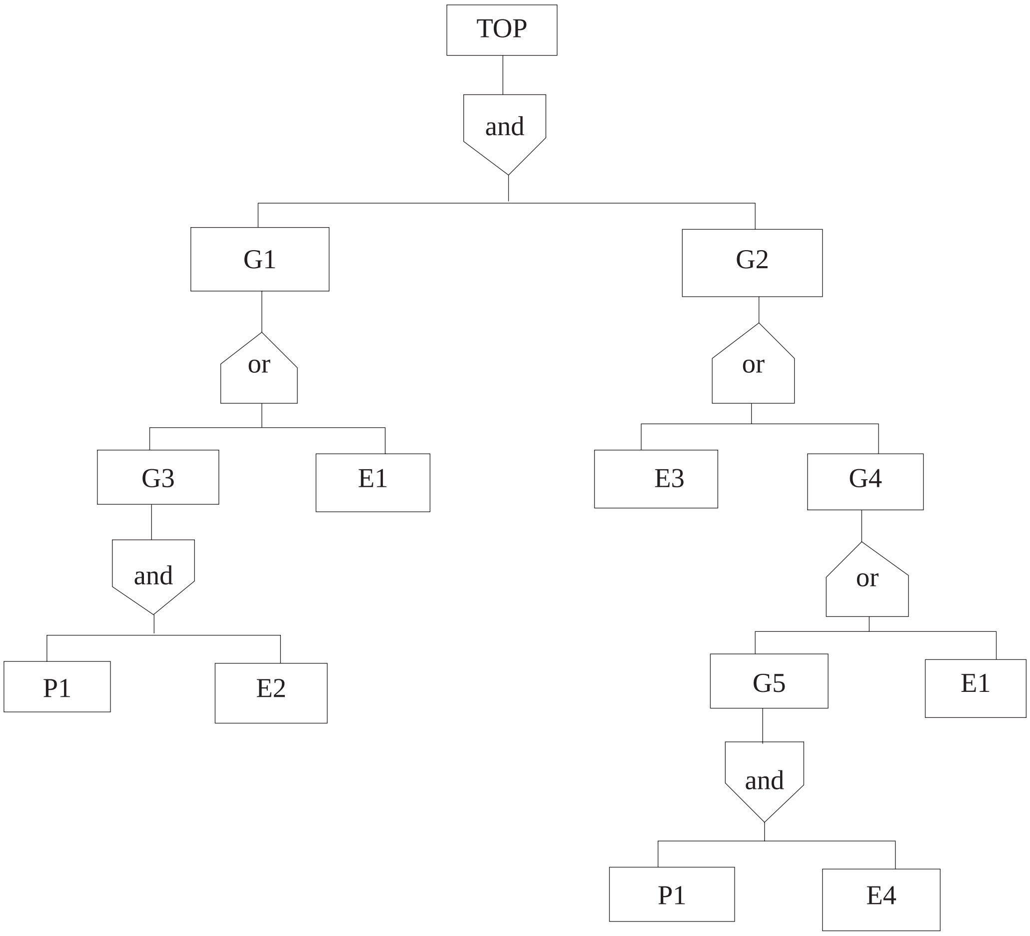
Advantages of using a Fault Tree

1. The main advantage of fault tree analysis compared with the conventional approach lies in the capability of displaying the relative importance of ecach comonent with respect to system reliability.

2. Minimal cut sets are used to identify the weakest points of the system in a qualitative sense.

3. Importance levels can be found to rank each component.

4. If complete independency among system components can be assumed, the fault tree analysis gives a good result. Thus, it is necessary to consider the problem of multisafe component failure and the extent of the applicability of fault tree methods to a wider range of problems.



Sensitivity Analysis

In order to analyse the sensitivity of fault trees, some of the probabilities of basic events, such as heavy weather, human error, shift of cargo and fish on deck are changed systematically. Example results are as follows:

In Table 1, the probability of heavy weather was changed and the effects of this were calculated. When the probability of heavy weather was changed from. 197E-4 to. 197E-5, the probability of loss of vessels changed from .577E-4 to .394E i.e. 32% . If the probability of heavy weather is decreased by 100, the probabiltiy of loss will not decrease as much as it decreased from 0.197E-4 to 0.197E-5. This is because other probabilities becomes dominant and heavy weather becomes unimportant. On the other hand, if the probability of heavy weather is very high, such as. 197-E-3, it becomes dominant and other probabilties become unimportant.

Table 1. Change in probabilities when probability of heavy weather is changed

Heavy Weather	.197E-6	.197E-5	.197E-4	.197E-3
Foundering	.231E-4	.248E-4	.426E-4	.219E-3
Fire and Exp.	.106E-5	.106E-5	.106E-5	.106E-5
Collision	.695E-5	.698E-5	.726E-5	.100E-4
Grounding	.648E-5	.651E-5	.676E-5	.958E-5
LOSS	.376E-4	.394E-4	.577E-4	240E-3

Table 2. Change in probabilities when probability of human error is changed

Human error	2.17E-5	2.17E-4	Change (%)
Foundering	.710E-5	.231E-4	69
Fire and Exp.	.680E-6	.106E-5	36
Collision	.657E-5	.696E-5	0.6
Grounding	.610E-5	.648E-5	0.6
LOSS	.204E-4	.376E-4	46

In Table 2, the probability of human error, which includes carelessness, was changed to see how it affects other probabilites such as foundering, fire and explosion, collision, grounding, and loss of vessels.

When the probability of human error was decreased by 10, the probability of loss of vesssels changed 46%, the probabiblity of foundering changed 69%, the probability of fire and explosion changed 36%, the probability of collision changed 0.6%, and the probabiltiy of grounding changed 0.6%. This table shows that human error has an important effect on the main causes of the loss of vessel such as foundering, collision etc.

From the results of sensitivity analysis, the following table can be established to show the importance level of some basic event (Köse 1991). As shown in Table 3, human error is the most important basic event to cause the loss of vessel, then, shift of cargo, fish on deck, and taking catch etc.

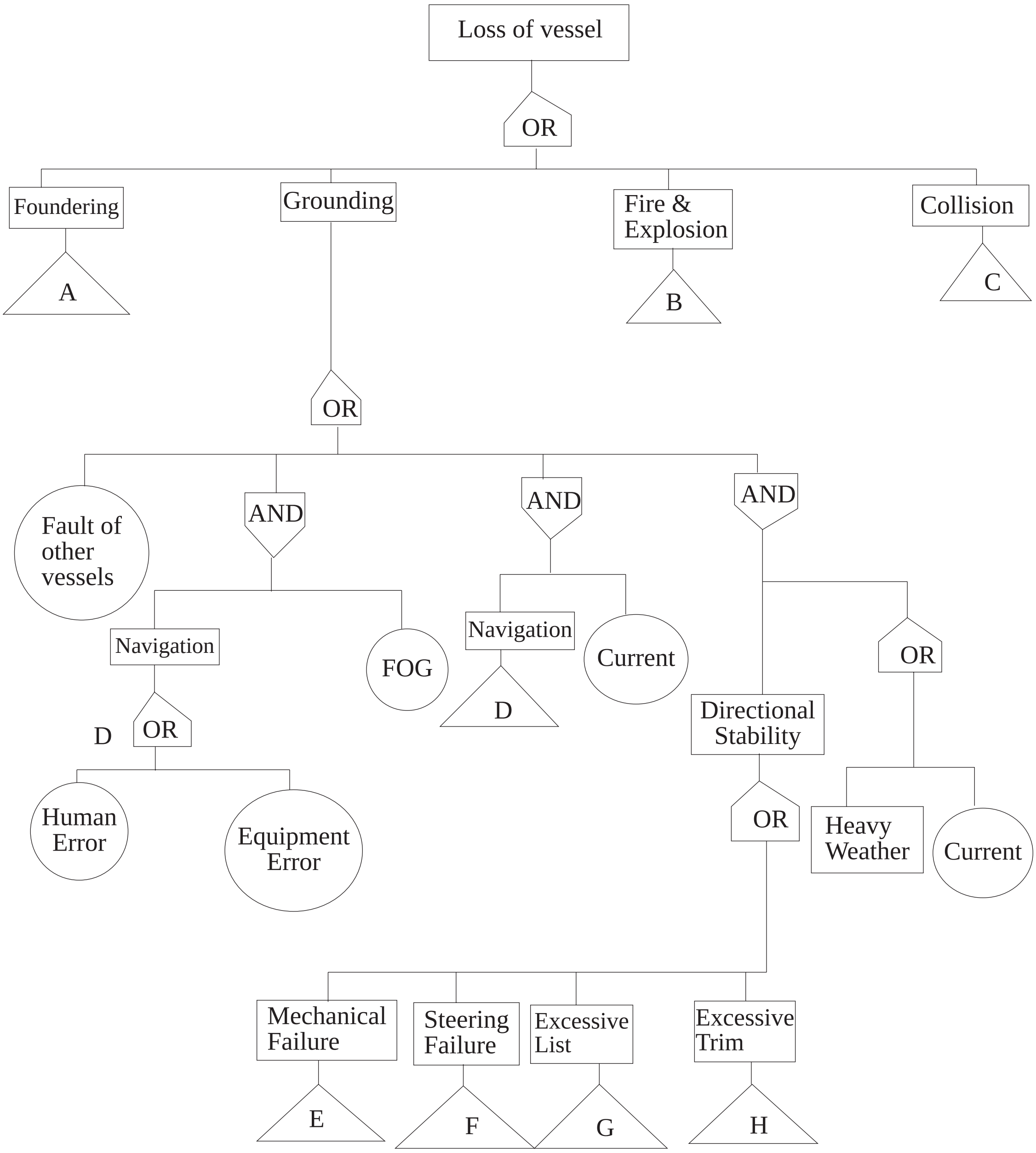


Figure 1a. Developed Fault Tree

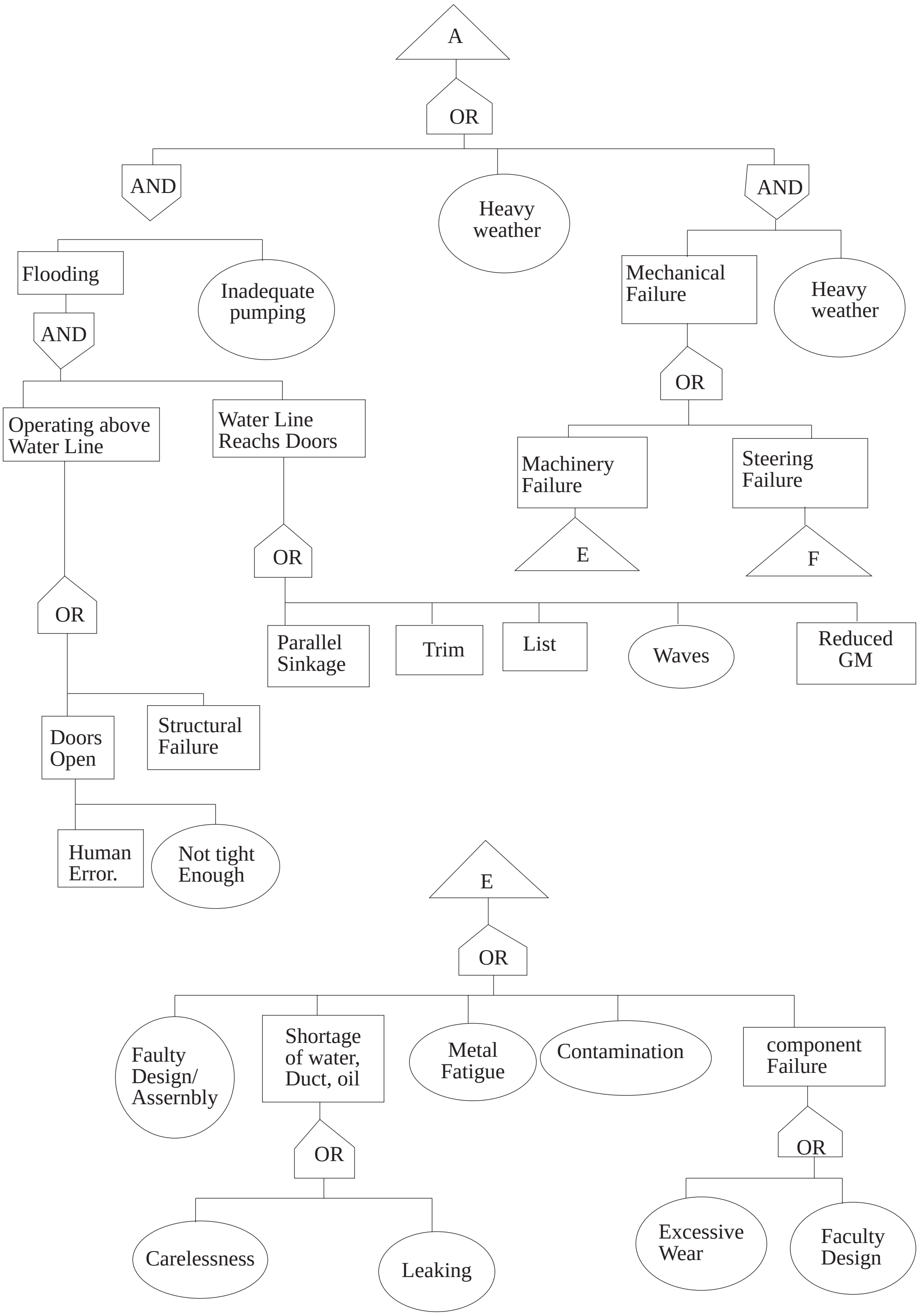


Figure 1b. Developed Fault Tree (continued)

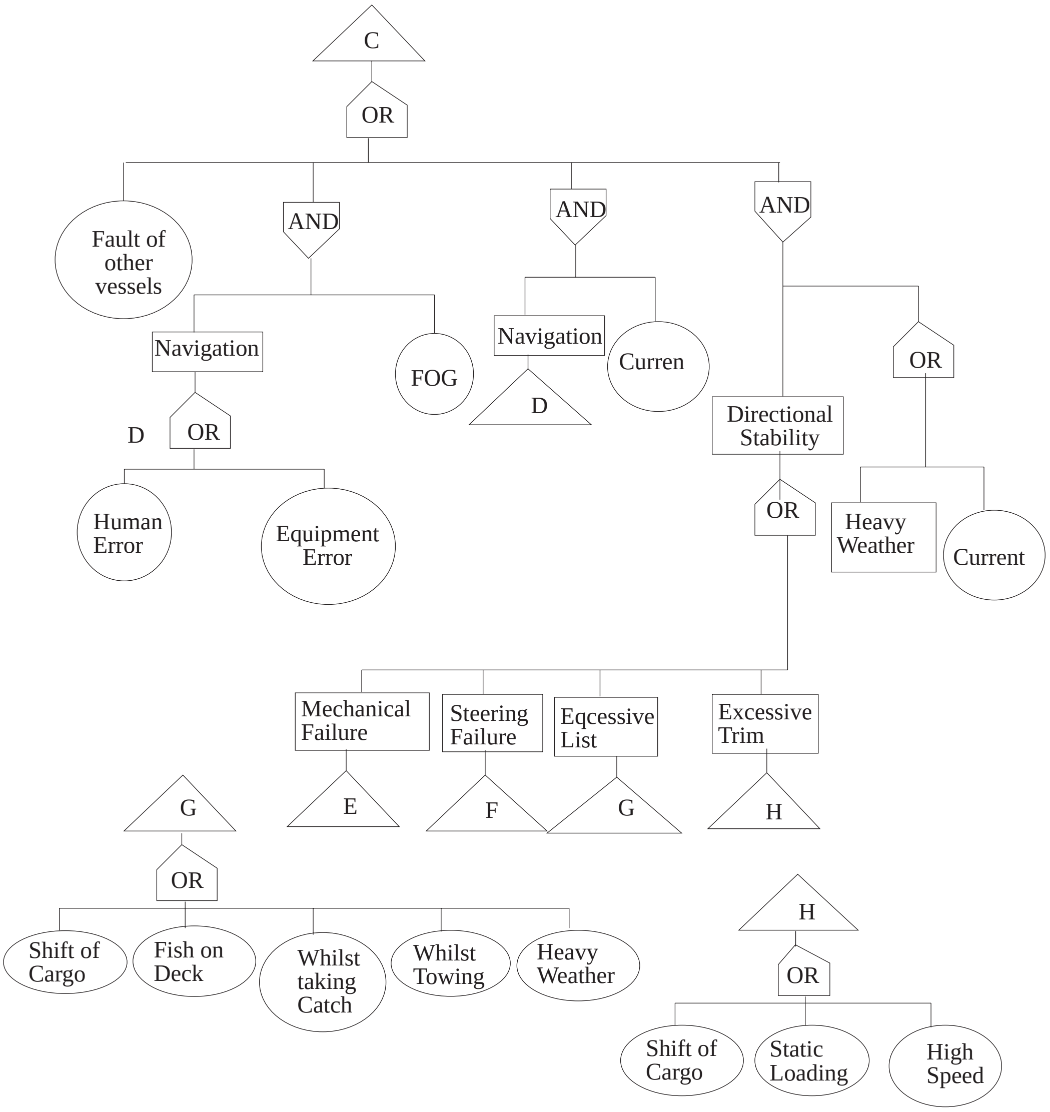


Figure 1c. Developed Fault Tree (continued)

Table 3. Change in probabilities o loss of vessels, when others have been decreased by 10 and increased by two.

	Changes in probabilities of loss of vessel (%)	
	decreased 10x	increased 2x
Human error	46	50
Shift of cargo	22	24.5
Fish on deck	22	24.5
Taking catch	8.77	9.57
Towing	8.77	9.57
Equipment error	0.2	0.27
Faculty design	1.6	1.86

In this study some of the probabilities were assumed, due to lack of data (such as probabilities of inadequate pumping, doors open, high speed etc.) Therefore, in order to analyse the effects of these assumptions, some further calculation were made after some probabilities were multipled by two (e.g. the probability of mechanical failure, steering failure, fire and explosion). The aim of this increase in some probabilities was to check how they affect the ranking of basic events, in other words, to see if human error was still the most important event followed by shit of cargo and so on (Köse 1991). As shown in Table 3, human error is the most important factor on loss of

Reasons for Human Errors

In this study, it is shown that human error is one of the most common type of error causing the loss of vessels. It is important to reduce human errors in order to improve safety.

Major human errors are:

1. Improper lookout
2. Rules of the road violation
3. Misjudged effects (wind, current, speed)
4. Failure to ascertain position
5. Failure to utilize available navigation equipment
6. Carelessness/inattention
7. Improper corrective procedures
8. Failure to determine height of wave
9. Crew asleep
10. Absorbed in secondary task
11. Watchkeeper distracted by non,routine event
12. Watchkeeper incapacitated on bridge (present but incapacitated by alcohol)

Tahe following fault tree is given as an example in the explanation of human error.

The following factors can contribute to human error:

1. Exposure to high level of noise and vibration
2. The combination of living and working in a moving vessel
3. Adverse climate and weather conditions
4. Stress factors due to catch quotas

Solution of an Educational and Organizational Nature

It is obvious that all the safety equipment in the world will not make a difference, unless the fishermen know how to use it. That is where training becomes important.

Human functions can be classified in three groups:

1. Skill-based
2. Rule-based
3. Knowledge-based

Solutions related to training would require a compulsory course. This course should be focused on all three human functions, and should cover knowledge of regulations and use of equipment. A qualified replacement for the skipper with additional crew on the bridge in difficult circumstances and an obligatory watchkeeper alarm (McDonald and Powers, 1989) should be required. In order to improve these three skills, fault tree analysis can be used as a training aid. It seems axiomatic that the more one knows about what causes accidents, the more will know how to prevent them. This application could involve the use of the fault tree as a tool for increasing awareness.

Solution of a Technical Design Nature

A New Instrument

Due to rapid developemnts in microelectronics and information technology, it is possible to reduce the probability of collision by installing a device linked to the radar which sets off an alarm when another ship comes too close. Such an intrument is already compulsory on ships of more than 10000 tons, but it is expensive. The fishing industry is an outstanding target group for extension of the use of this sort of insturment, but it will need to be reduced in cost.

If such an instrument were to be introduced, a number of residual risks and side effects should be considered (Hatfield, 1989)

The residual risk is determined to a great extent by the reliability of the collision alarm. To be credible, the radar and collision detector must be highly reliable, otherwise vessels witll not located or false alarms will lead to a lock of confidence in the alarm.

Noise

The concentration of the main and auxiliary power in the relatively small space on a modern diesel fishing vessel has lead to an increasing number of complaints by crews regarding the noise and its effects on their health, stress leevls, concentration and safety.

Fluidborne noise can be reduced by fitting hydraulic attenuators. These are compact device which can easily be installed in existing systems, and can last as long as the system.

Vibration

Exposure to mechanical vibration on board fishing vesels consists essentially of vibrations transmitted to the whole body. However, the following distinctions should be made (Hatfield, 1989):

1. Vibrations trasmitted via the feet of the seaman standing on one of the decks
2. Vibrations trasmitted to the whole of the seamans's body when he is lying down on the mattress of his bunk.
3. Vibrations transmitted through the seamans's seat when he is sitting.

In order to reduce human error, vibration and noise should be minimised because of their significant effects. For example, the crew would have difficulties in reading, writing and plotting charts, and resiting. The efficiency and attention of the crew could be affected.

Design of Bridge Layout

The following reasons show why the redesign of the bridge and equipment is necessary: (Pawlowski, 1987)

1. There are vast potential changes in hardware components due to the technological push of electronic equipment,

2. To roise the interest of the skippers/owners in the improvement of the fisihg vessel safety, their own working place is a profitable starting point.

3. In terms of cost-benefit, a high improvement rate is expected from bridge and equipment redesign in the reduction of fishing vessel collisions.

The following aspects should be considered for the desing of the bridge:

1. The average frequency o use of instruments should be a determining factor in their positioning
2. Grouping of instruments is useful to enable the comparison of information
3. Modification at the instrument level should be as follows:
   a) Automation of information transfer from one instrument to another is desirable
   b) Integration of information on one display instead of presentation on different display is possible
   c) Linkage between insturument is possible
4. Vision can be improved by illumination of equipment on the bridge and sight lines for several tasks with respect to navigation, decks and fishing gear can be improved.

Details of equipment can be improved.

The importance of equipment with regard to safety is relevant.

References

Aldwinckle, D.S. and Lewis, K.J., "Risk Analysis of future Floating Systems", RINA offshore engineering group int. sym. on development in floating production system. 1984

Caldwell, J.B. and Yang, Y.S., "Risk and Reliability Analysis applied to Şhip Çapsize: A preliminary study", Trans. RINA. 1985

Chaplin P.D., and Burney S., "Casualties to Fishing Vessels and Accident to man", Publications of the Department of Transport, U.K. 1988

Hatfield, S.F., "Fishing Vessel Safety-Stability Consideration", Int. Symp. On Safety and Working Conditions Aboard Fishing Vessels. Quebec, Canada. 1989

Köse, E., "Risk Assessment of Fishing Vessels,", MPhil Thesis, University of Newcastle upon Tyne, U.K. 1991

MacDonald, J.M., Powers, G.D., "USA Coast Guards Recent Activites in Commercial Fishing Vessel safety", Safety and Working Conditions aboard Fishing Vessels, Canada. 1989

Pawlowski M., "An Approximaiton to the righting Arm Curve", Department of Naval Architecture and Ocean Engineering Glasgow University report no: NAOE-87-50. 1987

Yang, L.S., "Marine Hazard Assesment", Ph.D. thesis Department of Naval Architecture and Shipbuilding, University of Newcastle upon Tyne. 1989