LIVERPOOL JOHN MOORES UNIVERSITY

LJMU Research Online

Pillay, A and Wang, J

Risk assessment of fishing vessels using fuzzy set approach

http://researchonline.ljmu.ac.uk/id/eprint/9759/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Pillay, A and Wang, J (2002) Risk assessment of fishing vessels using fuzzy set approach. International Journal of Reliability, Quality and Safety Engineering, 9 (2). pp. 163-181. ISSN 0218-5393

LJMU has developed **LJMU Research Online** for users to access the research output of the University more effectively. Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Users may download and/or print one copy of any article(s) in LJMU Research Online to facilitate their private study or for non-commercial research. You may not engage in further distribution of the material or use it for any profit-making activities or any commercial gain.

The version presented here may differ from the published version or from the version of the record. Please see the repository URL above for details on accessing the published version and note that access may require a subscription.

For more information please contact researchonline@ljmu.ac.uk

http://researchonline.ljmu.ac.uk/

RISK ASSESSMENT OF FISHING VESSELS USING FUZZY SET APPROACH

Dr. A. Pillay, Dr. J. Wang

Total pages: 22

Proofs: Dr J. Wang, School of Eng., LJMU, Byrom Street, L3 3AF, UK

Tel.: +44 151 231 2445

Fax: +44 151 298 2453

Email: j.wang@livjm.ac.uk

Abstract ─ The data available from fishing vessels are scarce and often accompanied with a high degree of uncertainty. For this reason the use of conventional probabilistic risk assessment may not be well suited. This paper proposes a method using fuzzy set theory (FST) to model the occurrence likelihood and consequences of failure for the identified hazards on a fishing vessel. The method uses fault tree analysis to calculate the fuzzy probability of the system failure. The consequences of failure for each basic event within the fault tree are considered for 4 different categories. The risk of the basic events is determined by combining the likelihood of occurrence and consequences of failure in linguistic terms and is further defuzzified to produce a risk ranking. The application of this method is demonstrated using a hydraulic winch operating system of a fishing vessel.

Keywords: fuzzy set, risk assessment, risk ranking, fishing vessel

1. Introduction

Risk is defined to refer to a probability distribution over a set of outcome [Banard, 1996]. When the outcomes in question are hazards or injuries, risk can be understood to refer to different potential severity of hazards or injuries.

Upon identifying the list of potential hazards and its contributing factors, which could be achieved by several methods including Hazard and Operability studies (HAZOP) [Villemeur, 1992], Failure Mode and Effect Analysis (FMEA) [MIL-STD, 1629A], Fault Tree Analysis (FTA) [Henley & Kumamoto, 1992] etc, the next step is to quantify these events for the risk estimation phase. Quantification of risk considers two parameters, namely,

1. Probability of failure event occurrence.
2. Consequence severity.

These are the two parameters that are considered in many risk assessments utilised by the industry at present [Preyss, 1995].

The frequencies of hazardous events are usually based on historical failure data. Often, little is known of the basis of the data or its processing and interpretation. The little that is known often raises doubts as to its quality, completeness and relevance. Even where data is of high quality, sample sizes are often small and statistical uncertainties are correspondingly large. As such, fuzzy set modelling approach may be more appropriate to model the probability of a hazardous event occurring.

The quantification of severity can be accomplished in several ways, subjective reasoning and expert judgement is one of the common methods. As accidents on fishing vessels are rarely reported, it may be difficult to quantify the severity of an accident. Once again, the use of Fuzzy Set Theory (FST) and expert knowledge is well suited for this purpose.

2. Background

Prof. Lofti Zadeh at the University of California first introduced FST in 1973 [Zadeh, 1973]. The significance of fuzzy variables is that they facilitate gradual transition between states and consequently, possess a natural capability to express and deal with observation and measurement uncertainties.

The membership function $\mu(x)$, gives the degree of membership for each element $\boldsymbol{x} \in \boldsymbol{X}$. $\mu(x)$ is defined on [0,1] (The actual degree of membership of a system parameter in a particular group is indicated by the values between 0 and 1 inclusive). A membership of 0 means that the value does not belong to the set under consideration. A membership of 1 would mean full representation of the set under consideration. A membership somewhere between these two limits indicates the degree of membership. The manner in which values are assigned to a membership is not fixed and may be established according to the preference of the person conducting the investigation.

3. A Proposed Approach

The proposed approach is divided into two main modelling categories, i.e. likelihood probability (Part 1) and severity of consequences (Part 2). It involves several steps, which are represented in the flowchart shown in Figure 1. A combination of FST and expert judgement is used to accomplish the modelling of the two parameters. The outcome of which is used to rank the risk associated with an event failure according to its priority. Part 1 of the approach uses FTA to identify the critical components of a system [Pillay A. et. al., 2000]. Using this FTA, fuzzy arithmetic calculation is performed on the basic events to obtain the fuzzy probability estimates of the primary events. The results are left in the linguistic state to enable integration with the analysis of severity of consequences.

In Part 2 of the approach, the severity of a failure is assessed for its effect on four categories, as will be discussed later. The results of the analysis in Parts 1 and 2 are combined using the min-max inference rule to obtain a linguistic term for the risk. This linguistic term is then defuzzified using the weighted mean of maximum method to produce the risk ranking.

The first step of the proposed approach is to establish the type of data that is available for analysis. Depending on the size and organisational structure of the company, this data will vary in terms of its format and availability. The data available from fishing vessels are most likely repair data that would just reflect the date the repair was carried out and the spares consumed. Such data should be restructured to enable analysis using fuzzy set approach.

The consequences of an event may not be documented in a format where it is readily useable for analysis. The severity of the consequence could be determined by the cost incurred from the result of the failure. This however may only be limited to equipment loss, production loss, environmental clean up cost etc. The injury or loss of life (due to the failure of an equipment) is normally expressed in terms of number of casualties and the extent of the injury i.e. bruises, required shore medical assistance, permanent disablement or death etc.

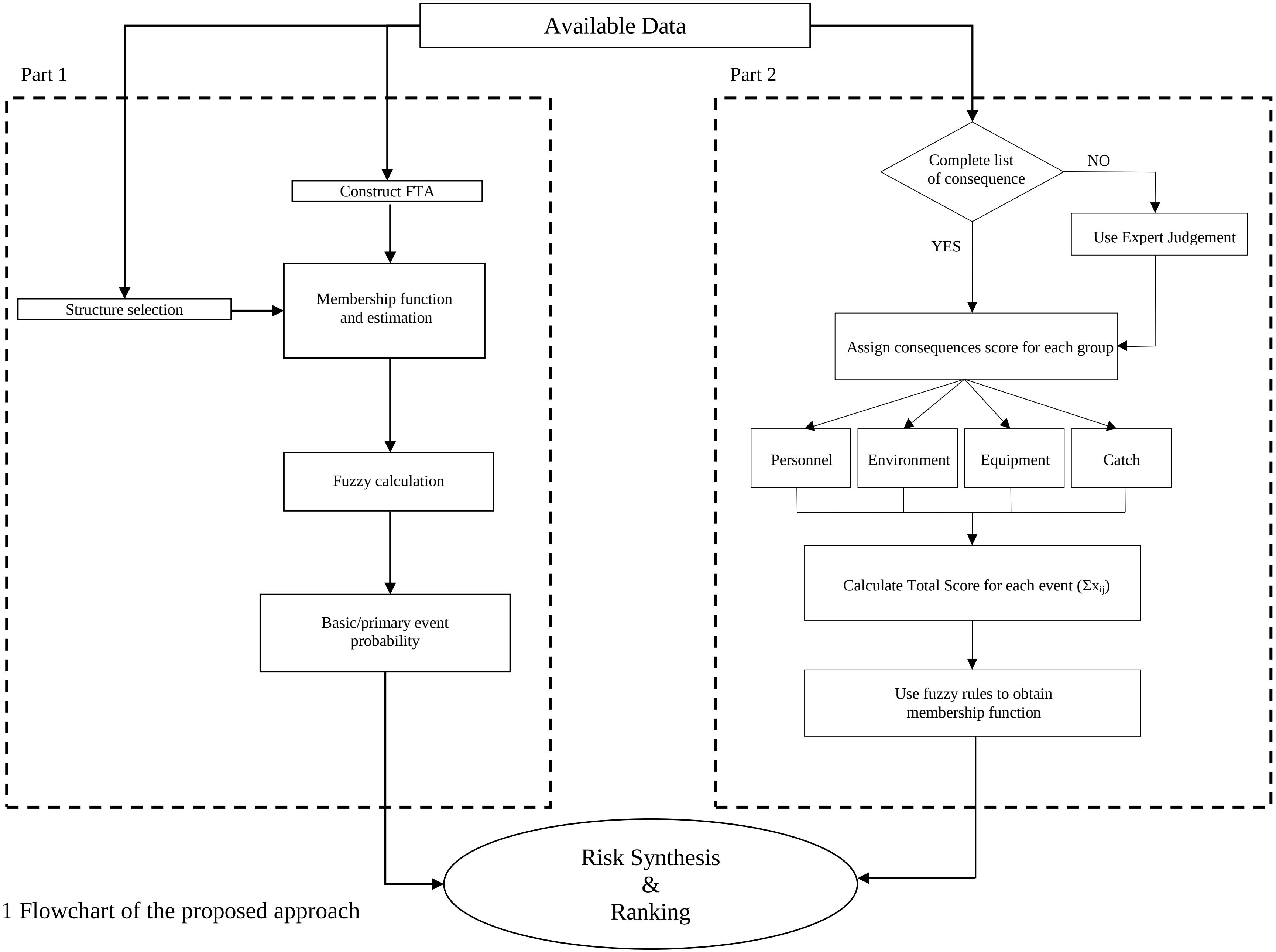


Figure 1 Flowchart of the proposed approach

3.1 Part 1: Probability of failure event occurrence

Constructing fault tree

Given the critical event or undesired condition (top event), a fault tree can be developed using backward logic to create a network of intermediate events linked by logic operators (usually AND and OR operators) down to the initiating basic events. The primary/basic events may be related to human error (operators, design or maintenance), hardware or software failures, environmental conditions or operational conditions.

Structure selection

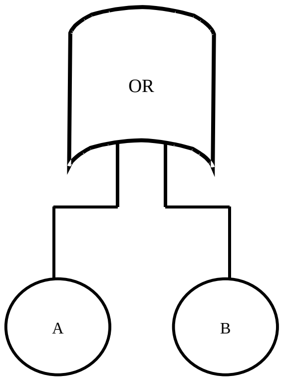
In the structure selection phase, the linguistic variable is determined with respect to the aim of the modelling exercise. Considering the available data at hand and the aim of this approach, the linguistic variable is determined to be the likelihood of occurrence of an undesired critical event i.e. the probability of failure occurring. The linguistic terms to describe this variable are then decided, e.g. Very High, High, Moderate, Low and Remote.

Membership function & estimation

Six classes of experimental methods help to determine membership function: horizontal approach, vertical approach, pairwise comparison, inference based on problem specification, parametric estimation and fuzzy clustering [Pedrycz & Gomide, 1998]. The method selected depends on the way the uncertainty is manifested and captured during the sampling of data. Due to the nature of the arithmetic involved, the shape of the membership function suited for the proposed approach would either be triangular or trapezoidal, therefore the horizontal or vertical approach for function determination is applied [Pedrycz & Gomide, 1998].

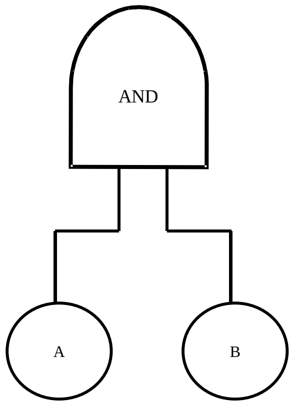
Fuzzy calculation in fault trees

When two basic events represent the input to an OR gate as shown in Figure 2, it can be assumed that these two events are in a series configuration. It denotes that the occurrence of either event will cause the OR gate to be operative. For an AND gate with two basic events as its input as shown in Figure 3, it can be considered that the two events are in parallel configuration. This denotes that only if both events occur, the AND gate will be operative [Bowles & Paláez, 1995].



$$\tilde{P}_{sys}=[1-(1-\tilde{P}_A)(1-\tilde{P}_B)]$$

Figure 2 OR gate



$$\tilde{P}_{sys} = \tilde{P}_A\tilde{P}_B$$

Figure 3 AND gate

3.2 Part 2: Consequence Severity

List of consequences

When carrying a comprehensive analysis, it is important that all the consequences of a failure be considered. It has been noted that due to the poor documentation of accidents on fishing vessels, the list of identifiable consequences are limited to the serious or life threatening ones. Therefore, expert judgement should be used to compile a list of consequences and complement the historical data. This can be achieved in the form of a FMEA [Smith, 1992]. The analyst has to assign consequences for each event/failure into their respective groups. In the proposed approach, four groups have been identified, that is, Personnel, Equipment, Environment and Catch. For each event or failure, a rating from 1 - 4 is given for each of the groups. The ratings describe the consequences of an event occurring in linguistic terms such as ‘Negligible’, ‘Marginal’, ‘Critical’ and ‘Catastrophic’. The significance of each of the ratings are listed and described as follows:

Personnel:

Effect of failure of the item on personnel (worst case always assumed).

Rating 1 = Negligible (No or little damage- bruises/cuts)

Rating 2 = Marginal (Minor injuries - treatable on board)

Rating 3 = Critical (Major injuries – requires professional attention)

Rating 4 = Catastrophic (Death/permanent disablement)

Environment:

Effect of failure of the item on the environment

Rating 1 = No effect (No or little effect)

Rating 2 = Marginal effect (Can be controlled by ship-staff)

Rating 3 = Critical effect (Requires shore assistance)

Rating 4 = Catastrophic effect (permanent damage to the environment)

Equipment:

Effect of failure on machinery or system in terms of down time if failure occurs and cost of repair.

Rating 1 = Negligible (No or little attention needed - cleaning up/drying)

Rating 2 = Marginal (Minor repair – few hrs lost)

Rating 3 = Critical (Major repair – few days lost)

Rating 4 = Catastrophic (Destruction of equipment - Total plant shutdown)

Catch:

Effect of failure on fishing operation in terms of catch effected: -

Rating 1 = No effect (No or little effect)

Rating 2 = Marginal effect (Catch affected for a few hours)

Rating 3 = Critical effect (Catch affected for a few days)

Rating 4 = Catastrophic effect (No catch for a few months)

Calculate Total Score (Σx_{ij})

Upon assigning a score for each group, a table is generated as shown in Table 1. From this table, a 'Total Score' is calculated by summing the score of each individual group for an event. This total score will later be used to assign the membership function for that event using fuzzy rules.

	Personnel	Environment	Equipment	Catch	Total Score(ΣX_{ij})
Failure Y_1	X_{11}	X_{21}	X_{31}	X_{41}	ΣX_{i1}
Failure Y_2	X_{12}	X_{22}	X_{32}	X_{42}	ΣX_{i2}
Failure Y_3	X_{13}	X_{23}	X_{33}	X_{43}	ΣX_{i3}

Table 1 Event Score

Fuzzy rules

The fuzzy rules determining the membership function of each event are divided into 4 categories i.e. Hazard Class 1(HC_1), HC_2, HC_3 and HC_4. The maximum score of an event is used to assign that particular event to the appropriate hazard class. Therefore, if an event has a score of [2,2,1,1] for each group respectively, it would be assigned to HC_2 (the maximum score for that event is 2 for the Personnel and Environment categories).

Fuzzy rules are generated based on available historical data, experience and complemented by expert knowledge. Following are a sample of such rules:

Hazard Class 1 (HC_1)

If an event has a score of [1,1,1,1], which entails that for all categories considered, the effect of the failure is negligible, then the total effect of that failure on the system and environment should be negligible as well. Hence,

1) If $\Sigma X_{ij} = 4$, then Negligible…………….(1.0)

Hazard Class 2 (HC_2)

The minimum score possible in the HC_2 category is 5, i.e. [2,1,1,1] or any variation of this score. The maximum possible score is 8, i.e. [2,2,2,2], therefore the range of membership function between these two extremities is assigned so as to ensure a smooth transition between limits to have overlapping of functions. Hence: -

2) If $X_{ij\ max} = 2$, and $\Sigma X_{ij} = 5$ then 0.8 Negligible, 0.6 Marginal………(2.0)

$\Sigma X_{ij} = 6$ then Marginal, 0.2 Critical……………...(2.1)

$\Sigma X_{ij} = 7$ then 0.5 Marginal, 0.8 Critical………….(2.2)

$\Sigma X_{ij} = 8$ then Critical, 0.2 Catastrophic………….(2.3)

The above rules can also be seen in Figure 4.

Hazard Class 3 (HC_3)

The minimum score possible in the HC_3 category is 6, i.e. [3,1,1,1] or any variation of this score. The maximum possible score is 12, i.e. [3,3,3,3]. When assigning the linguistic membership function for HC_3, it is important to compare the values with that of the HC_2 to ensure that it does not contradict the rules generated for that hazard class. For the same total score in HC_2 and HC_3, the linguistic membership function for HC_3 (for that particular score) should logically reflect a more severe consequence. For example, for a total score of 7 for HC_2 and HC_3, which would have a combination of [2,2,2,1] and [3,2,1,1] respectively, using expert judgement, one would say that although both classes have the same total score, a total score of 7 for HC_3 would entail a more severe consequence. Hence the membership function for HC_3 and a total score of 7 would be 0.8 Critical, 0.2 Catastrophic which is higher than the membership function for HC_2 with the same total score of 7, which is 0.5 Marginal, 0.8 Critical. Using this method, the rules for HC_3 are generated for the other values of its total scores and are reflected as below:

3) If $X_{ij\ max} = 3$, and $\Sigma X_{ij} = 6$ then 0.5 Marginal, Critical……………………….(3.0)

$\Sigma X_{ij} = 7$ then 0.8 Critical, 0.2 Catastrophic………………(3.1)

$\Sigma X_{ij} = 8$ then 0.5 Critical, 0.5 Catastrophic………………(3.2)

$\Sigma X_{ij} = 9$ then 0.2 Critical, 0.8 Catastrophic………………(3.3)

$\Sigma X_{ij} = 10$ then Catastrophic………………………………(3.4)

$\Sigma X_{ij} = 11$ then Catastrophic………………………………(3.5)

$\Sigma X_{ij} = 12$ then Catastrophic………………………………(3.6)

The above rules can also be seen in Figure 5.

Hazard Class 4 (HC_4)

4) If $X_{ij\ max} = 4$, and $\Sigma X_{ij} \geq 7$ then Catastrophic……………………………….(4.0)

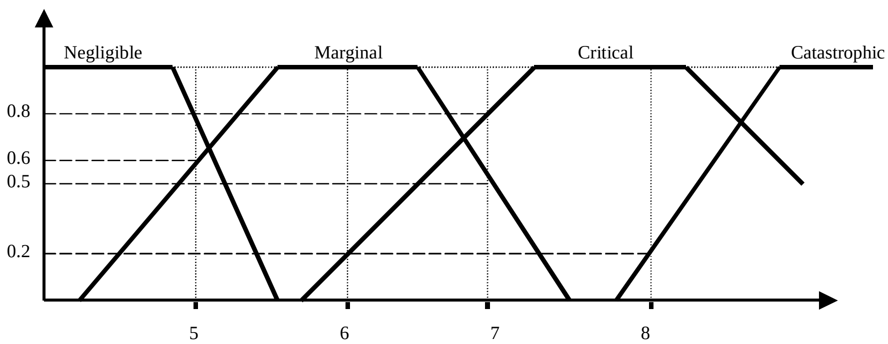


Figure 4 Hazard Class 2

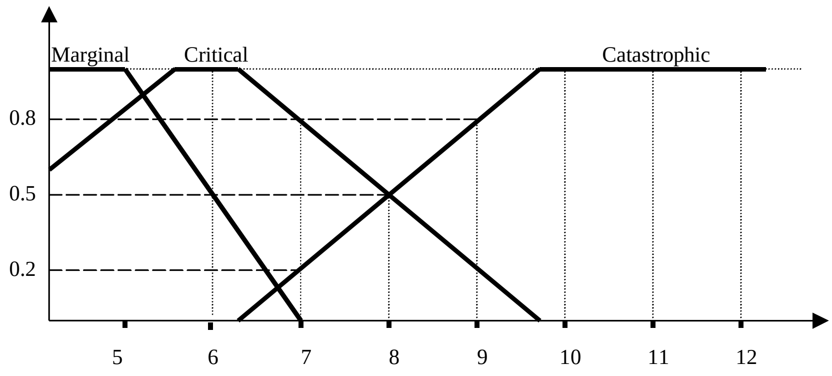


Figure 5 Hazard Class 3

Grouping each event into a hazard class allows direct comparison with other events and enables the effects of a failure to be compared based on its linguistic terms assigned to it. For example, if an event A has a score of [3,3,1,1] and a total of 8 and event B has a score of [2,2,2,2] which also gives a total of 8, from experience and expert judgements, it can be said that event A is more serious in nature. Hence, it should be assigned a linguistic term which must be 'more severe' compared to event B. Therefore, the membership function for event A and B will be obtained from Rule No.(3.2) and (2.3) respectively.

3.3 Risk Assessment

The risk associated with a failure increases as either the severity of the consequences of the failure or the failure probability increases. The severity of an event is ranked according to the seriousness of the effect of the failure. Judgement of the severity of a failure consequence is, by its very nature, highly subjective.

Using a priority matrix, the "riskiness" of a failure can be obtained. The risk posed by the failure is expressed in linguistic terms such as *'Very Important', 'Important', 'Moderate'* and *'Low'*. This matrix is based on the probability of occurrence and the severity of the consequence. Table 2 displays the various combinations of these two parameters.

The interpretation of hazard risk ranking is given as below:

- Very Important $\Rightarrow$ Needs immediate corrective action.
- Important $\Rightarrow$ Review and corrective action to be carried out.
- Moderate $\Rightarrow$ Review to be carried out and corrective action implemented if found to be cost effective.
- Low $\Rightarrow$ Review subject to availability of revenue and time.

From this table, a risk ranking in linguistic terms can be obtained for the failure of a system/sub-system or component. For example, if the probability of failure is *'High'* and the severity is '*Marginal*', then the risk would be classified as '*Important'*. In order to utilise this information for the decision making process, a crisp number has to be obtained from the linguistic terms to rank the risk according to its priority. One common procedure for ranking risk is to use the RPN or 'Risk Priority Number'. This method provides a numerical ranking for each term and multiplies them to assess the riskiness [Loughran et. al., 1999].

		Severity of Occurrence			
		NEG	***MARG***	***CRIT***	***CAT***
Probability of Occurrence	***REMOTE***	**RN**	**RM**	**RC**	**RCAT**
	LOW	**LN**	**LM**	**LC**	**LCAT**
	MODERATE	**MN**	**MM**	**MC**	**MCAT**
	HIGH	**HN**	**HM**	**HC**	**HCAT**
	VERY HIGH	**VHN**	**VHM**	**VHC**	**VHCAT**

Very important

Important

Moderate

Low

Table 2 Probability and consequence matrix

Fuzzy set approach provides a more flexible and meaningful way of assessing risk. The analysis uses linguistic variables to describe severity and probability of occurrence of the failure. These parameters are ‘fuzzified’ to determine their degree of membership in each input class using the membership functions developed. The resulting fuzzy inputs are evaluated using the linguistic rule base to yield a classification of the ‘riskiness’ of the failure and an associated degree of membership in each class. This fuzzy conclusion is then defuzzified to give a single crisp priority for the failure.

Figure 6 shows the membership function of the riskiness of an event on an arbitrary scale, which would later be used to defuzzify the fuzzy conclusion and rank the risk according to a priority number. The membership function used is a triangular function which is developed using the horizontal approach [Pedrycz & Gomide, 1998] based on expert judgement. Unlike the trapezoidal function, the membership value of 1 in the triangular function is limited to only one value of the variable on the x-axis.

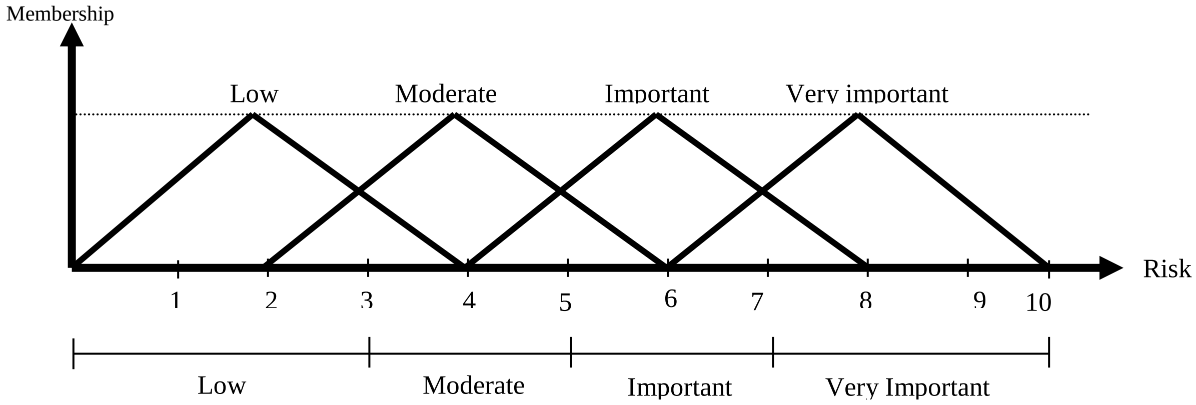


Figure 6 Membership function of riskiness

Rule Evaluation

Rules are evaluated using min-max inferencing to calculate numerical conclusion to the linguistic rule based on their input value [Zadeh, 1992]. The result of this process is called the fuzzy risk conclusion.

The ‘truth value’ of a rule is determined from the conjunction (i.e. minimum degree of membership of the rule antecedents) [Zadeh, 1973]. Thus the truth-value of the rule is taken to be the smallest degree of truth of the rule antecedents. This truth-value is then applied to all consequences of the rule. If any fuzzy output is a consequent of more than one rule, that output is set to the highest (maximum) truth-value of all the rules that include it as a consequent. The result of the rule evaluation is a set of fuzzy conclusions that reflect the effects of all the rules whose truth values are greater than zero.

Consider the risk priority table where the probability of occurrence is '*High'* and the severity is '*Marginal'* and having a membership function of 0.6 and 1.0 respectively. Thus the conclusion Riskness = '*Important'* has a membership value of min (0.6,1.0) = 0.6. To establish how risky the hazard is, this fuzzy conclusion has to be defuzzified to obtain a single ‘crisp’ result.

Defuzzification

The defuzzification process creates a single assessment from the fuzzy conclusion set expressing how risky the hazard is, so that corrective actions can be prioritised. Several defuzzification techniques have been developed [Runkler & Glesner, 1993]. One common technique is the weighted mean of maximum method, which is illustrated here. This technique averages the points of maximum possibility of each fuzzy conclusion, weighted by their degrees of truth.

The following is given to demonstrate how riskiness is obtained. Suppose Event A has the following probability of occurrence and severity of consequences:

Probability of Occurrence – **Moderate** (0.6 High, 1.0 Moderate, 0.5 Low).

Severity – **Marginal** (1.0 Marginal).

Then from the risk priority table (Table 2), Event A will be denoted by the prefix **MM** and therefore is associated with a riskiness of '**Important'.** However, considering all the membership functions of the two parameters, i.e. probability of occurrence and severity, the following terms of riskiness are generated:

0.6 High, 1.0 Marginal = HM = 0.6 Important

1.0 Moderate, 1.0 Marginal = MM = Important

0.5 Low, 1.0 Marginal = LM = 0.5 Moderate

From Figure 6, the support value for each linguistic term is obtained. Hence:

The support value for Moderate = 4
The support value for Important = 6

The weighted mean (Z) = [(1.0)(6) + (0.5)(4)]/(1.0+0.5)

= 5.33

From this result we can prioritise the riskiness of Event A as being "***Important***" with a support of **5.33.**

4. Application to a hydraulic winch system

To demonstrate the proposed approach, data from a fishing vessel is used as a test case. The data collected for the test case is in the format of repair data. It includes:

- Voyage no (shows the date when the repair was carried out).
- Equipment repaired.
- Parts that were changed.
- Modifications that were made.
- Cause of failure (in some instances).

Specialists/contract workers carry out the repairs for this particular vessel, in the floating dock. Should a failure occur during operation at sea, temporary repair is carried out by the crew and the equipment is kept operating in the ‘abnormal’ condition. No records are kept of any temporary repairs done on board, however, a repair list is compiled by the Chief Engineer for the equipment to undergo permanent repair work at the next ‘docking’.

In order to use this data for the modelling process certain assumptions were made:

- Repairs and modifications are only carried out when the equipment/component had failed.
- Upon completion of repair, the equipment is assumed to be "same-as-new".

For this test case the trapezoidal function was selected and estimated. The boundaries of the trapezoidal function were determined for each set. These values being the values of x for the respective α-cuts are subjective and were predominantly based on the policies and attitude of the company and on what the company thought to be tolerable limits within which they wish to operate. To describe the probability of occurrence, linguistic terms such as "Very High", "High", "Moderate", "Low", and "Remote" are used. A range of limits quantifying the probability of occurrence is then assigned to each term. These limits are in the form of Mean Time To Failures (MTTF). MTTF is given by:

$$MTTF = \frac{\sum t_i + \sum s_i}{n} \qquad (1)$$

where: t_i = time to failure, s_i = survival time and n = number of failures. These limits are then converted into failure rates by the following formula:

$$\lambda = \frac{1}{MTTF},$$

It is assumed that the failure process follows an exponential distribution and each test is conducted independently and in a series process. A failure rate is calculated under the assumption that the mean down time and repair time is very small compared to the operating time. It is reflected along an ordinal scale as shown in Table 3. The membership function used is a trapezoidal function, which is developed using the horizontal approach [Pedrycz & Gomide, 1998]. This function allows a membership value of 1 for a range of probabilities unlike the triangular function. This function is thought to model the probability of occurrence close to what it is in reality. Figure 7 shows the membership function along with its ordinal scale. The limits and the centre point values of the ordinal scale are given by the dotted line and will be used to perform the fuzzy arithmetic.

Probability (Linguistic term)	*MTBF range (days)*	*Failure rate (ordinal scale)*
Very High	1 to 5	1 to 2 x 10^{-1}
High	5 to 50	2 x 10^{-1} to 2 x 10^{-2}
Moderate	50 to 500	2 x 10^{-2} to 2 x 10^{-3}
Low	500 to 2000	2 x 10^{-3} to 5 x 10^{-4}
Remote	2000 to 10000	5 x 10^{-4} to 1 x 10^{-5}

Table 3 Probability range for linguistic terms.

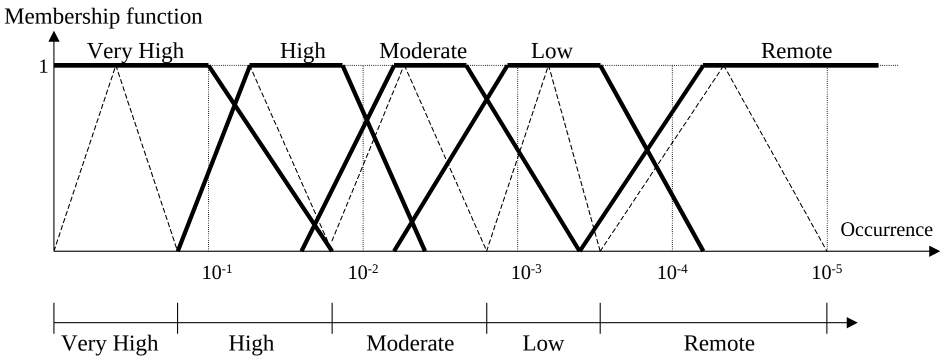


Figure.7 Membership function and ordinal scale

The system used to demonstrate this methodology is an operating system of a Gilson Winch on board an ocean trawler. This trawler is a 1266 GRT (Gross Tonnage), deep-sea trawler with an L.O.A (length overall) of 60 meters. The Gilson Winch is hydraulically operated and is situated forward of the Main Winches. Once the Main Winches have hauled the catch onto the ramp of the vessel, the Gilson Winch is used to drag the net closer towards the hatch to unload the catch onto the conveyors[1].

Table 4 shows the failure data of the primary/basic events for a Gilson Winch failure. The data collected is over a period of 66 months (14 voyages), and from this data, the linguistic term for failure probability of each basic event is determined by identifying the number of occurrences per operating day(s) on the ordinal scale. The membership function is then determined by reading off the intersecting points on the y-axis.

[1] The conveyors transport the fish to the fish factory below deck to begin the processing cycle.

Basic Events	*MTBF (days)*	*Linguistic term*	*Membership function*
Pipe flange leak	900	Low	0.5 Mod, Low, 0.1 Rem
Pipe	450	Moderate	0.6 High, Mod, 0.5 Low
Control valve fail	900	Low	0.5 Mod, Low, 0.1 Rem
Filter choke	40	High	0.72 V.High, High, 0.18 Mod
Brake cylinder fail	750	Low	0.5 Mod, Low, 0.1 Rem
Brake seal fail	300	Moderate	0.6 High, Mod, 0.5 Low
Clutch cylinder fail	900	Low	0.5 Mod, Low, 0.1 Rem
Clutch seal leak	900	Low	0.5 Mod, Low, 0.1 Rem
Air cylinder fail	900	Low	0.5 Mod, Low, 0.1 Rem

Table 4 Probability of basic events for Gilson Winch failure

Once the failure data has been gathered, it is grouped and sorted by its equipment/sub-system and finally the system to which the component belongs to enable a fault tree to be constructed. The top event of the fault tree will be the failure of the equipment (Gilson Winch failure) while the initiating events and basic events will be the component failure (seal leakage, brake failure, control valve failure etc). It is best to construct a fault tree for equipment within a system separately as it enables data handling and analysis to be conducted. The individual fault trees can later be collated to analyse the system failure. Fault tree construction can be achieved with the use of computer software packages such as Fault Tree +V6.0 and AvSim+ [Fault Tree +, 1995; AvSim+, 1998].

The fault tree shown in Figure 8 is generated from the data collected for the failure of the Gilson Winch. Each secondary or intermediate event (e.g. brake failure, clutch failure, hydraulic leakage etc) is modelled by gathering the available failure data and then grouping them according to the component or system they affect. For example, the failure of the brake cylinder (GBCyl) and brake seal leakage (GBSeal) will cause the brake to fail. Hence, the Brake Failure (G.Brake) is the secondary event with the GBCyl and GBSeal being its basic events. To demonstrate the application of this methodology with an example, the fault tree used only traces the path of failures that have been known to occur in the past, rendering the system inoperable.

Take two basic events from the fault tree in Figure 8, GBCyl and GBSeal as an example. The occurrence rates for GBCyl and GBSeal are 1 failure in 750 days and 1 failure in 300 days respectively. Therefore event GBCyl would have a fuzzy probability of *Low* and GBSeal, *Moderate.* Performing the arithmetic operation on both these events will yield the result of 0.62 *High*, *Moderate* and 0.46 *Low* for the secondary event, brake failure (G.Brake). Figure 9 shows a graphical representation of this. This can be interpreted as the secondary event belonging to the linguistic term *High* with a membership of 62%, complete membership (100%) to *Moderate* and *Low* with a membership of 46%.

Similarly, all the basic events in the fault tree are analysed in this manner producing an end result for the top event. The Gilson Winch failure has a fuzzy failure probability of *HIGH* with a membership function of 0.9 Very High, 0.84 High and 0.1 Moderate. Although the membership to the *Very High* linguistic term is the highest, when the result is defuzzified to reflect the range of probability which it belongs to, it falls into the *High* category on the ordinal scale. It can therefore be stated that the failure rate of the Gilson Winch lies between 2 x 10^{-1} and 2 x 10^{-2}.

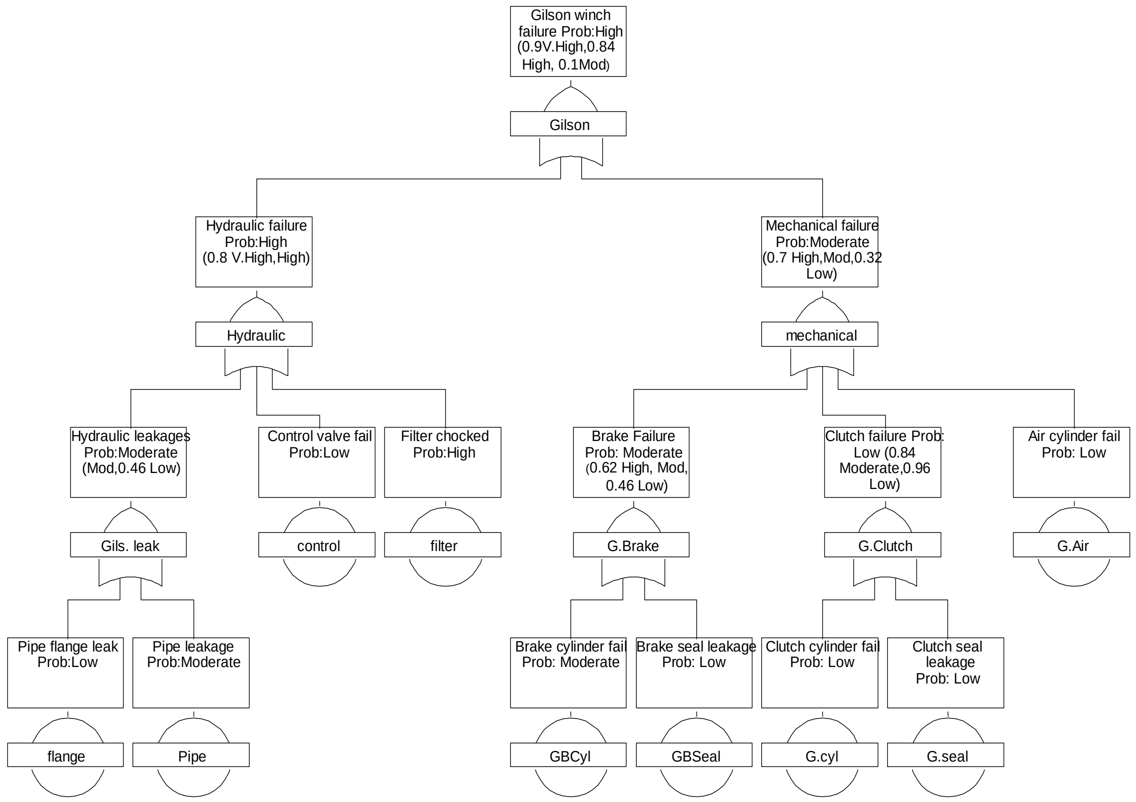


Figure 8 Fault tree of Gilson winch failure

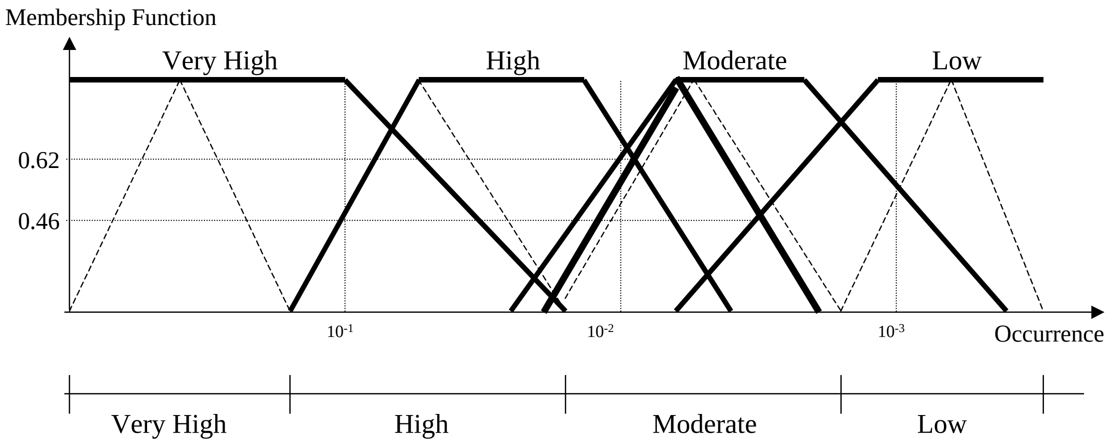


Figure.9 Graphical representation of fuzzy arithmetic operation on two basic events

Consequence severity modelling

The amount of data that was available on the consequences of a failure was scarce and difficult to come by. However, much of the data was in terms of cost and reports of accidents and incidents that lead to injuries. Since there is no standard format for reporting an accident, the data was obtained from telexes, faxes, superintendent reports, Chief Engineers' logbook and various other sources. To complement the data, expert knowledge and judgement was used to assign ratings to each group i.e. Personnel, Environment, Equipment and Catch. Table 5 shows the analyses of various failures in a Gilson Winch system.

	Personn.	***Environ.***	***Equip.***	***Catch***	***Total***	***HC***	Membership function
Pipe Flange leak	1	2	1	1	**5**	**2**	0.8 Neg, 0.6 Marginal
Pipe leak	1	2	1	1	**5**	**2**	0.8 Neg, 0.6 Marginal
Control v/v fail	1	1	2	3	**7**	**3**	0.8 Critical, 0.2 Catastrophic
Filter choke	1	1	1	3	**6**	**3**	0.5 Marginal ,Critical
Brake cyl fail	1	1	3	3	**8**	**3**	0.5 Critical, 0.5Catastrophic
Brake seal leak	1	1	2	2	**6**	**2**	Marginal, 0.2 Critical
Clutch cyl fail	1	1	3	3	**8**	**3**	0.5 Critical, 0.5Catastrophic
Clutch seal leak	1	1	2	2	**6**	**2**	Marginal, 0.2 Critical
Air cyl fail	1	1	1	1	**4**	**1**	Negligible

Table 5 Gilson Winch event failures

Risk Ranking of the Hydraulic Winch System

The probability of occurrence is determined for each basic event (Table 4) and the severity of the same basic events is as shown in Table 5. The risk estimation and ranking of these basic events can be carried out. For the pipe flange leak event, the probability of occurrence was determined to be 0.5 *Mod*, *Low* and 0.1 *Rem*, and the severity as 0.8 *Neg* and 0.6 *Marg.* Using the rule evaluation method described above, which is summarised here in Table 6, the linguistic term for risk is determined.

From Table 6, the risk evaluation for the pipe flange failure can be summarised as being (0.5 Low, 0.5 Imp, 0.8 Low, 0.6 Mod, 0.1 Low and 0.1 Low).

Probability of occurrence	***Severity***	***Risk***
0.5 Moderate	0.8 Negligible	0.5 Low
0.5 Moderate	0.6 Marginal	0.5 Important
Low	0.8 Negligible	0.8 Low
Low	0.6 Marginal	0.6 Moderate
0.1 Remote	0.8 Negligible	0.1 Low
0.1 Remote	0.6 Marginal	0.1 Low

Table 6 Risk evaluation for pipe flange failure

Weighted mean for event pipe flange leak is calculated as follows:

$$Z = \frac{\mathbf{(0.8\ x\ 2) + (0.6\ x\ 4) + (0.5\ x\ 6)}}{\mathbf{(0.8 + 0.6 + 0.5\ )}} = \mathbf{3.68}.$$

Therefore from Figure 6, the event “Pipe Flange Leak” will be prioritised by “**Moderate”** with a support value of **3.68**. Similarly, the risk evaluation for all other basic events is carried out. The results of the evaluation are shown in Table 7. Table 8 shows the results of the calculations for the weighted mean for all the other events within the system.

Events	*Occurrence*	*Severity*	*Risk*
Pipe Flange leak	0.5 Mod, Low, 0.1 Rem	0.8 Neg, 0.6 Marg	0.8 Low, 0.6 Mod, 0.5 Imp
Pipe leak	0.6 High, Mod, 0.5 Low	0.8 Neg, 0.6 Marg	0.8 Low, 0.6 Mod, 0.6 Imp
Control v/v fail	0.5 Mod, Low, 0.1 Rem	0.8 Crit, 0.2 Cat	0.2 Mod, 0.8 Imp, 0.2 V.Imp
Filter choke	0.72 V.High, High, 0.18 Mod	Crit, 0.5 Marg	0.5 Imp, V.Imp
Brake cyl fail	0.5 Mod, Low, 0.1 Rem	0.5 Crit, 0.5 Cat	0.1 Mod, 0.5 Imp, 0.5 V.Imp
Brake seal leak	0.6 High, Mod., 0.5 Low	Marg, 0.2 Crit	0.5 Mod, Imp, 0.2 V.Imp
Clutch cyl fail	0.5 Mod, Low, 0.1 Rem	0.5 Crit, 0.5 Cat	0.1 Mod, 0.5 Imp, 0.5 V.Imp
Clutch seal leak	0.5 Mod, Low, 0.1 Rem	Marg, 0.2 Crit	0.1 Low, Mod, 0.5 Imp
Air cyl fail	0.5 Mod, Low, 0.1 Rem	Neg	Low

Table 7 Failure events of a Gilson Winch

Event	*Risk (Linguistic term)*	*Support value*
Filter choke	**Very Important**	**7.33**
Clutch cyl fail	**Important**	**6.72**
Brake cyl fail	**Important**	**6.72**
Control v/v fail	**Important**	**6.00**
Brake seal leak	**Important**	**5.65**
Clutch seal leak	**Moderate**	**4.50**
Pipe leak	**Moderate**	**3.68**
Pipe flange leak	**Moderate**	**3.68**
Air cyl fail	**Low**	**2.00**

Table 8 Ranking of failure events of a Gilson Winch

5. Conclusion

Lack of reliable safety data and lack of confidence in safety assessment have been two major problems in safety analysis of various engineering activities. This is particularly true in Formal Safety Assessment (FSA) due to the fact that level of uncertainty is high. In ship safety assessment it may often be difficult to quantify the probability of undesired events occurring and the associated consequences of effect due to this very reason.

The proposed approach addresses these concerns and offers an alternative solution. Its application can be extended to sub-systems within an operating system to generate a list of components, which are ranked according to their priority for attention. This can help the owners and operators of fishing vessels to improve operating and maintenance strategies. This approach can be adopted within the FSA framework for generic ships and the results obtained from the analysis can be further utilised in step 4 of the FSA [Marine Safety Agency, 1993].

Acknowledgement

The authors would like to thank Mr. T. I'Anson of Boyd Lines Ltd who supplied the data of a fishing vessel for the test case, Mr. Loughran from the Maritime and Coastguard Agency for useful discussions in fishing vessel safety and the HEFCE (NFF) and ORS for financial support of the research project.

References

AvSim+ (1998), Version 7.03, Isograph Limited.

Banard R.C. (1996), " A New Approach To Risk Assessment Integrating Scientific Evaluation And Economic Assessment Of Cost And Benefits", Regulatory Toxicology and Pharmacology 24, pp 121-125.

Bowles J.B. & Paláez C.E. (1995), "Application Of Fuzzy Logic To Reliability Engineering", Proceedings of the IEEE, Vol 83, No.3.

Fault Tree+ (1995), Version 6.0, Isograph Limited.

Henly E.J. & Kumamoto H. (1992),"Probabilistic Risk Assessment", IEEE Press, New York.

Kaufman A. and Gupta M.M. (1991), "Introduction To Fuzzy Arithmetic", Van Nostrand Reinhold.

Klir G.J. & Yuan B. (1995), "Fuzzy Sets And Fuzzy Logic: Theory And Application", Prentice-Hall.

Loughran C.G., Pillay A., Wang J. (1999), "Formal Safety Analysis Of A Generic Fishing Vessel", Plymouth International Conference of Fishing Vessel Safety, 12-15 April.

Marine Safety Agency (1993), "Formal Safety Assessment MSC66/14", Submitted by the United Kingdom to IMO Maritime Safety Committee.

MIL-STD-1629A, "Procedures For Performing A FMECA, Military Standard", Naval Ship Engineering Centre, Washington D.C.

Pedrycz W. & Gomide F. (1998), "An Introduction To Fuzzy Sets, Analysis And Design", MIT Press.

Pillay A., Wang J., Wall A.D. & Ruxton T. (2000), "Analysis Of Fishing Vessel Failure Data Using Fuzzy Set Approach", Proceedings of ESREL 2000, SARS and SRA-Europe Annual Conference, Vol.2, Edinburgh 15-17 May 2000, ISBN: 90 5809 140 6, pp. 1005-1013.

Preyssl C. (1995), "Safety Risk Assessment And Management-The ESA Approach", Reliability Engineering and System Safety, 49, pp 303-309.

Runkler T.A and Glesner M. (1993), "A Set Of Axioms For Defuzzification Strategies Toward A Theory Of Rational Defuzzification Operators", Proceedings of the 2nd IEEE International Conference on Fuzzy Set System, pp 1161-1166.

Smith D.J. (1992), "Reliability, Maintainability And Risk", 4th Edition, Butterworths-Heineman Limited.

Villemeur A. (1992), "Reliability, Availability, Maintainability and Safety Assessment", John Wiley, Chichester.

Zadeh L.A. (1973), "The Outline Of A New Approach To The Analysis Of Complex Systems And Decision Process", IEEE Transactions On System, Man and Cybernetics, Vol. SMC-3, pp 28-44.

Zadeh L.A. (1992), "The Calculus Of Fuzzy If/Then Rules", AI Experts, pp 23-27.