STABILITY FAILURE ANALYSIS IN THE OPERATIONS OF FLOATING DRY DOCKS

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SUMMARY

The main area of this work reflects a topic for which there is little or limited reference available and is carried out to meet the needs of professional and practical floating dry dock operators. The risk of hazards in floating dry docks is evaluated using a discrete fuzzy set theory (FST) and an evidential reasoning (ER) approach in a situation where historical failure data is not available. Fuzzy set modelling is used to estimate the safety levels of the causes of basic failure events in floating dry docks due to stability concerns using the concept of linguistic variables, and provides a framework for dealing with such variables in a systematic way. The ER approach is used to synthesise the estimated safety levels of the causes of hazards/basic hazard events. The results of this work will be valuable to dry dock masters and sister maritime engineering professionals.

NOMENCLATURE

S_i	Risk/safety score of the i^{th} event
F^{CP}	Failure consequence probability
F^L	Failure likelihood probability
O	Fuzzy composition operation
X	Fuzzy cartesian product operation
C^s	Consequence severity
μ	Fuzzy set distribution function
D	The unscale distance
α	Value of D for any given distance
β	Extent to which S_i belongs
S_{im}	Probability masses
S_{i1H}	Degree of base event role
$T^m{}_i$	Resultant Degree of belief
P	The unscaled numerical value
Q_i	Crisp value of safety expression

1. INTRODUCTION

The need for shipboard maintenance has never been more important than in an age of International Safety Management (ISM) principles. Ships needing maintenance below the waterline, require the major facilities of the Dry Dock, and as a consequence the 'docking industry' has matured to what it is today (House, 2003). Not only are there many types of docking facilities, but these have also grown to match the expansion of the shipping industry by accommodating ever larger vessels. A typical example of this is a floating dry dock.

Floating docks are used mainly for ship repair work. The capacity of floating docks is between 1 and 900NM and there are no technical limitations in this capacity range. In modern layouts, floating docks are equipped with gantry cranes ensuring greater flexibility during the repair or exchange of large parts of the ship under repair (Mazurkiewcz, 1980). These docks, because of their generally restrictive size, have a tendency to cater for smaller tonnage and specialised type vessels such as small coasters, dredgers, fishing vessels, research vessels etc. (House, 2003). Floating docks are themselves constructed to classification requirements, and are often placed in a larger dry dock, as and when essential maintenance is required.

Generally, these floaters are of sufficient size, strength, displacement and stability to lift a vessel from the water using buoyancy. These docks are operated with a list and trim to reduce blocking loading and to reduce or eliminate vessel stability problems when docking or undocking (Harren, 2010). According to (Wasalaski, 1982), accidents involving floating dry docks have raised concerns about the rated lifting capacity and stability during dry docking operations. Hence, MIL-STD-1625D (2009) called for renewed attention to the safety problems of floating dry docks in regard to stability and buoyancy.

Indeed, the task that is critical for the proper operation of a floating dry dock is that of risk assessment. An important step in advancing our knowledge requires us to understand and address risks (Ngai & Wat 2005). According to (Leung, Chuah & Tummala, 1998), most floating dry dock project managers worry about the time involved in risk management when it comes to identifying and assessing risks. However, with the aid of computers and use of risk analysis software systems, the time for risk analysis can be significantly reduced.

Risk analysis can be conducted by using the theory of probability, which estimates the likelihood and consequences of any given risk. Docking and undocking operations have only limited information available with associated risks. The application of discrete fuzzy set theory (DFST) and evidential reasoning (ER) to risk analysis seems appropriate as such analyses are highly subjective and related to inexact and vague information.

This research describes the development of a subjective approach in risk analysis that can be used to effectively support dry dock project managers in conducting risk assessment. The motivation for the present work is the recognized absence and need for such system that helps in the evaluation of a company's risk level and provides the overall evaluation of a floating docking and undocking operation.

The structure of this paper herein includes: Section 2 as the statement of problem. This elaborates the need of the problems that might arise in a typical floating dry dock due to stability failure; Section 3 presents a typical review of the various scenarios that can lead to stability failure in floating dry dock such as stability calculation errors, failure to adhere to buoyancy and stability limits, multiplication effects, lack of understanding of intact stability, lack of compartmentation, and damage condition; Section 4 presents the application of discrete fuzzy evidential reasoning in other maritime section; Section 5 is the mathematics of discrete fuzzy evidential reasoning (Mwaoha *et al*, 2011); Section 6 presents a framework of fault tree - discrete set theory and evidential reasoning; Section 7 carries out an illustrative study on possibility assessment of a floating dry dock stability failure using proposed framework; Section 8 is recommendation for decision making on possible risk control options identified in this study.

2. STATEMENT OF PROBLEM

One requirement of a floating dock is to float without excessive heal or trim in water and to return to its original position of equilibrium once disturbed. Secondly, it must be able to withstand the forces and moments imposed on it in service without sinking and without excessive heel or trim. Thirdly, the system must be able to withstand a reasonable amount of flooding as the result of damage without sinking while accepting that no floating dry dock can be completely save (Tupper, 2013). Some problems however exist when a ship is docked on a floating dry dock system for repair. The first is to decide the standards of stability required to ensure the aims of the operation are met. Secondly, the surviving normal in service conditions is complicated by the conditions such as, the displacement and amount of fluids in tanks variation, the sea state variation and wind directional strength variation (Tupper, 2013).

In trying to meet the aim of a floating dry dock surviving an accident, the above uncertainties apply to the conditions at the time of the incident. Whilst various measures of floating dock stability can be assessed and standards set, these do not directly give the probability that the floating dock might be lost (Tupper, 2013).

A full investigation of floating dry dock stability is complex, and even with the power of modern computers, some assumptions and approximations must be made. In order to study stability methodically the following is considered (Tupper, 2013):

- The intact stability of the floating dry dock in still water at small angles.
- The extension to stability at larger angles of inclination and the features of the stability curves obtained are compared with those for previous successful floating ships.
- The behaviour of the floating dock in wind and waves.
- The flooding, loss of stability, and the risk of loss following an incident and compartmentation.

Based on floating docking experiences, the position and extent of damage are expressed subjective probabilistic terms such as the likely sea and wind conditions at the time. It is therefore important for the dry dock master and operators to understand the need to review every consequence of stability failure from a perspective of the system under various conditions.

3. STABILITY FAILURE REVIEW

A floating dock must have adequate stability to carry out its normal operations and to survive a reasonable amount of flooding allowance damage. There are methods for calculating a number of criteria related to dry dock stability in small and large inclinations in the intact state. These criteria are compared with acceptable standards based on those criteria. These standards, however, do not directly show the degree of risk losing a dry dock. Probabilistic methods are now used to access dry docks damage stability (Tupper, 2013).

Unlike other types of dock structures, a floating dry dock must not only have the strength and dimensions for docking a vessel, it must also be stable throughout the entire docking and undocking procedure. The real danger of course is when the vessel may become unstable while the dock is flooding or being drained, or when the ship is either departing or arriving, respectively (Heger, 2005).

The need for an adequate 'metacentric height' to compensate for the virtual rise of the ships centre of gravity once the vessel takes the blocks is well recognised. The danger associated with slipping off the blocks when entering or leaving, could be considerable, as well as being highly dangerous for persons on board and in the immediate vicinity of the dry dock equipment, internal ballast water, mud and the ship. To insure stability, the ship/dock combination must maintain a minimum metacentric height throughout the evolution. The metacentric height is a measure of ship stability, and it varies with dock's size (House, 2003).

Calculations which takes into account, all the ships compartments and their respective weights are noted, yet draughts and trim factors affecting the vessel throughout the docking and undocking periods are monitored closely. In some cases, if the list should develop, the risk of dislodging the bilge or keel blocks before the keel makes contact with centre line blocks must be considered an extremely dangerous and undesirable situation (Heger, 2005). It is prudent that all factors that would cause a vessel to be inclined during the period of any dock operation should be investigated (House, 2003).

Other factors under consideration such as high freeboard ships will be inclined by the force of strong wings, while wave action could generate roll motion to a long vessel part, and excessive rudder movement could also cause a roll tendency to affect the vessel while manoeuvring. The desire throughout is to achieve a safe docking (undocking) operation and to this end personnel involved in stability calculations should check carefully that the criteria being input is accurate and reliable to ensure correct results (House, 2003).

Most accidents attributed to instability occur during the undocking of the vessel because the changes in weight have not been monitored and the new stability characteristics were not recalculated, because the only way to ensure that the vessel will be stable is to keep track of weight changes on the vessel (Heger, 2005). This overview provides some basic understanding on various risk analysis issues and possible risk control options in investigating a floating dry dock stability failure.

3.1 STABILITY EVALUATION PROCESS

It is normal for the vessel intending to dry dock to have a small trim by the stern. When a ship is partially supported by the dock blocks, its stability will be different from that when floating freely (Figure 1) and it must be investigated (Heger, 2005).

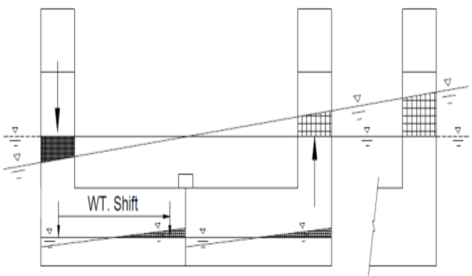


Figure. 1: Water planes (House, 2003)

The amount of trim expected is usually advised by the Dry Dock Manager and this would be usually be a figure which is compatible with the line of blocks, so that the keel will make a small angle. As the water level drops, the ship trims until the keel touches the blocks over its entire length. It is then that the force on the stern frame or after cut-up will be greatest and the stability most critical (Tupper, 2013).

In other words, from the moment the keel first touches the blocks (critical instant) the weight supported by the blocks is the difference between the displacement (when fully waterborne) and the displacement to the waterline in grounded. The stability of the ship/dock system is most appreciated for 5 separate phases of the docking and undocking procedure outline in the dry dock manual by House (House, 2003). These phases include; dry dock at full submergence-no ship, partial list of ship-ship has been lifted approximately ½ its docking draft, external waterline at top of the keel blocks, external waterline just over pontoon deck and lastly dock at normal operating draft.

In line with water plane, the stability for a floating dry dock is not only a function of the water plane but by the dock's wing wall. In the minimum stability phase, only the wing walls cut the water plane and provide the stability. As the dock take a list, the wing wall on the lower side gets deeper in the water and a stabilizing buoyant force develops which tries to right the dock. The wing on the high side is losing buoyancy which also has a stabilizing effect. The wider and further away from centreline the wing is, the more stable the dock is (Heger, 2005).

3.2 STABILITY CALULATION

As water drops further, the ship will be steadied by the breast shores. The effect of taking the blocks directly affects the ship's distance from metacentre of centre of gravity i.e. the 'GM' value and could be compared to a weight being removed from the area of the ship's keel. The basic stability element is presented in Figure 2. As the vessel become sewn overall on the blocks this becomes the most critical phase, part of the ships weight is borne by the blocks and part is borne by the residual water about the hull. As pumping continues and the hull dries, the full ships weight is then taken up by the blocks (House, 2003).

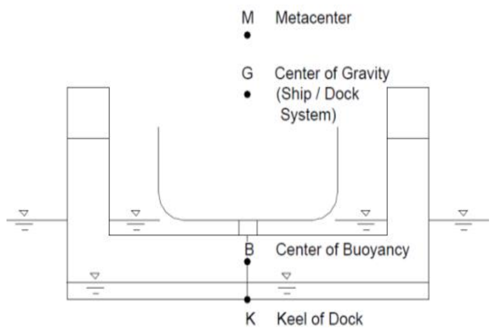


Figure. 2: Points of Stability (House, 2003)

The following equation is used to calculate stability, GM=KB+BM-KG. 'KB' = the height of the vertical centre of buoyancy of the immersed portion of the dry dock above the docks keel. 'BM' = the height of the transverse metacentre above the vertical centre of buoyancy and is equal to the net moment of transverse inertia divided by the displace volume (V). 'KG' = the height of the centre of weight of all components of the ship/dock system above the docks keel.

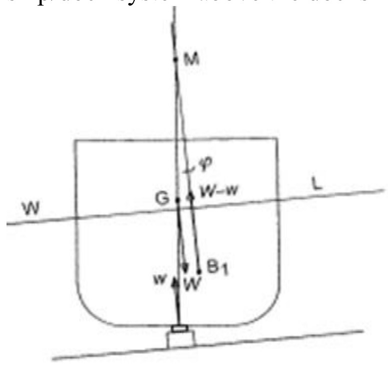


Figure. 3: Righting moment (Tupper, 2013)

The danger throughout the docking operation is where a vessel has a low value of GM or may incur even a negative GM value at the critical instant, and start to generate a list, before the bilge blocks and shores can be positioned. Such circumstances are highly undesirable (House, 2003). Suppose the force at the time the keel touches along the whole length is '*w'* and that it act on a distance '*x'* aft of the centre of flotation. Then, if '*t'* is the change of trim since entering dock: $wx = t$ (MCT) seen in Figure 3 (Tupper, 2013).

The value of '*w'* can be found using the value of moment of change trim (MCT) read from the hydrostatics. Referring to Figure 3, the righting moment, '*R*' acting on the ship assuming a very small heel, '*φ*',

$$
\begin{aligned}
R &= (W-w)\,GM \sin\varphi - wKG \sin\varphi \\
&= [WGM - w(GM-KG)] \sin\varphi \\
&= (WGM - wKM) \sin\varphi \\
&= [GM - w/W(KM)]\, W \sin\varphi
\end{aligned}
$$

Should the expression inside the brackets become *'negative'*, the ship will be unstable and my trip over. Whilst the breast shores will hold the ship to a degree, if held loosely the ship may slip off the blocks. With any '*positive GM'* the ship/dock system will be stable.

The minimum required for any unknowns when evaluating the docking can be difficult to ascertain. Typical unknowns are the '*exact vessel KG'*, the '*weight*', the '*free surface effects on the vessel*', the '*docking KG'* and the '*dock weight*'. A curve of minimum GM as required by both ABS (ABS, 2009) and U.S Navy's MIL-STD-1625 (2009) Certificate Program presented in Figure 4, aids in determining these unknowns for any particular floating dock type in its underlining operation.

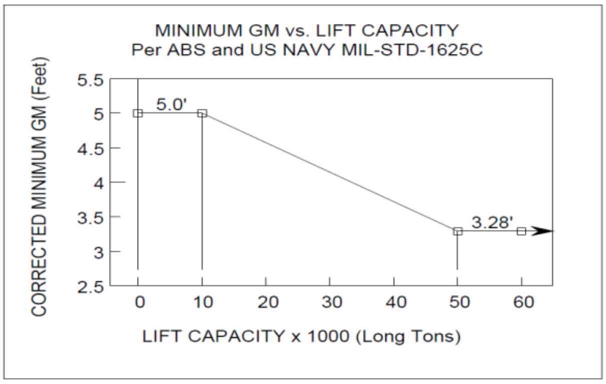


Figure. 4: Minimum GM vs. Lift Capacity (ABS, 2009)

Ship stability calculations not only rely on ship's geometry but also on the knowledge of where the ship's centre of gravity (G) from the keel can be ascertained for various conditions that the ship may be in House (2003). Just as in a ship, the free liquids in the large ballast tanks of a dry dock greatly reduce stability. A wedge of water shifts from high side to low side, where the effect occurs. This shifts the centre of gravity towards the low side which tends to increase the list – a de-stabilising effect (Heger, 2005). Away from stability calculation is an experiment for stability check called '*an inclining experiment'*. This experiment is based on two facts: (1) a displacement and (2) the position of 'G', in a known ship's condition. The environment of the dry dock is ideal for performing such a stability check, which involves moving weights across the vessel when in still water. A detail explanation of the purpose and experimental preparations are discussed in the dry dock manual by House (House, 2003).

Due to the complexity of stability calculation, in summary experts within the floating dry dock industry have encouraged the use of a '*Kg vs. Weight Curve'* which turns to correct the effect of water-plane. It is extremely important to adjust the 'GM' for water contained in floating dry dock tanks. To ease stability evaluation process, all floating dry docks should have a 'KG vs. Weight' curve. The curve is developed for a particular dry docks minimum stability phase. Once this curve is developed, any vessel's weight and KG adjusted (for free liquids) can be plotted as seen in Figure 5.

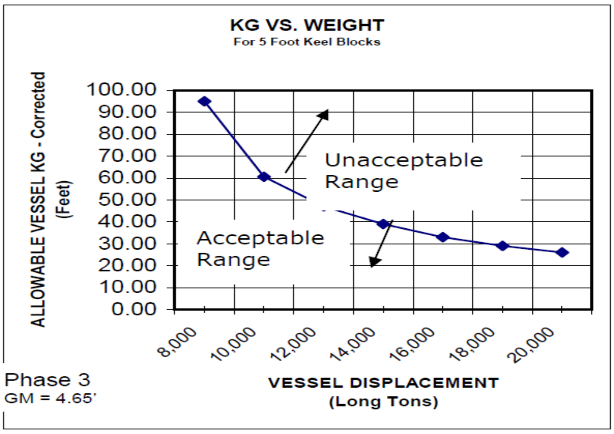


Figure. 5: Kg vs Wieght Curve (Heger, 2005)

If it plots below the curve then stability for that particular vessel is acceptable. If it plots above the curve then stability is unacceptable and the docking should not be performed. When using the curve be sure to note the height of keel block used in developing the curve and adjust the results if the height of keel actually used is different than the one used in the curve (Heger, 2005).

3.3 BUOYANCY AND STABILITY LIMITS

In considering the capability of a facility to dry dock a ship, two of the main factors affecting safety are the '*buoyancy*' and '*stability limits*'. To determine the lifting capacity of a floating dry dock, the following limits are considered; physical characteristics, structural limits, and buoyancy and stability limit (Wasalaski, 1982). MIL-STD-1625D (2009) was prepared as a guide for certifying floating dry docks to establish the maximum size each dry dock can safely dock. In reviewing MIL-STD-1625D (2009), there are two major parts are 'the design limits' and 'a review of the operation of floating dry docks as related to 'lifting capacity'.

According to Becht and Heger (2006) the stability of the ship-dock system is a critical factor, and must be considered in the design and the operation of a floating dock. This is true because the difference between a floating dry dock and other kinds of dry docks is that the forces between the blocking and the ship are a function of the floating dock's buoyancy as well as the ship's load.

Ship stability concerns not only rely on the ship's geometry but also on knowledge of where the ships 'centre of gravity' (G) are positioned. Although the distance of 'G' from the keel can be ascertained for various conditions that the ship may be in, it is essential that it is accurately known for one specified ship condition (House, 2003).

The dangers of avoiding low value of GM during docking generated list at critical instant led to the Vigor accident seen Figure 6. Such circumstance is considered as highly undesirable where by dry dock sinks and tug capsizes raised some concerns in the industry. Another stability concerns in Vigor accident was ship wrong stability calculations (GCaptain, 2013).

Figure. 6: Vigor stability concerns (GCaptain, 2013)

Grounding instability, occurring when the ship first touches the blocks, can be crucial, especially for ships with large amount of trim. Ship stability and altitude considerations as they pertain to the risk analysis are highly recommendable. As a result, the total weight of the ship and its distribution on the blocks must be known to ensure safe docking. Also, stability of the dock itself must also be sufficient at each phase of lifting the vessel out of water (Becth & Robert, 2006).

3.4 MULTIPLICATION EFFECTS

The change in the stability characteristics of the dry dock as the dock is submerged and the large water plane of the pontoon deck is lost can have a dramatic effect on the operation of the dock (Becth & Robert, 2006). This is called the '*multiplication effect'* and is calculated as the ration of the GM of the ship-dock system before the pontoon deck submerges to the GM of the ship-dock system after the pontoon deck is submerged. This effect is of concern only as the dock is submerged, not during the lift of a vessel, because when lifting the effect is the inverse of the ratio. The dock operator may slow the flooding rate and/or operate the dock on a longitudinal trim to reduce the transition rate and minimise the impact of the multiplication effect during the operation. The dimensions of the dry dock will determine the ratio and the impact of this phenomenon (Becth & Robert, 2006).

3.5 INTACT STABILITY

The dimensions of the wing walls and the compartmentation of the pontoon provide the stability for a ship-dock system, and the intact stability must be assessed for all phases during a docking operation. When the vessel's keel breaks the water's surface, the centre of gravity of the systems is very high, and the positive inertia, now being provided only by the docks wings, is at the minimum. Until the pontoon deck breaks the water surface, stability is at its minimum. This is the critical phase of *intact stability*, and the dimensions of the wing walls and the ballast tanks must be coordinated with the dock's design vessel (s) to ensure positive stability characteristics.

3.6 DAMAGE CONDITION

Floating dry docks demand stability analysis for the dry dock in a damage conditions. The impact of this requirement on the design of the dry dock is that the structure will need more compartmentation and larger wing walls than would be required for intact stability considerations alone (Becth & Robert, 2006). Buoyancy, structural, or intact stability limitations may be secondary to the restrictions on safe docking capacity dictated by these damage-stability requirements (Wasalaski, 1982). In this study, the damage condition can be investigated before and after an accident has occurred. The criteria of risk that can lead to the occurrence of instability in the floating dock is noted.

3.7 COMPARTMENTATION

The compartmentation of the pontoon provides for more precise control of the dry dock, in addition to enhancing the stability. Differential ballasting of the dry dock's ballast compartments permits a more equal and opposite reaction to the loading imposed by vessel, reducing stresses in the dry dock and vessel structure during a dry-docking. Also, the docks attitude can be adjusted by differential deballasting to accommodate a vessels list and/or trim (Becth & Robert, 2006).

3.8 COST OF STABLITY FAILURE

Once an accident occurs due to stability concerns in floating dry dock operations, damage may well be inflicted not only on property but also to human life and so forth. The operating cost and the invisible impact on goodwill are harmful to floating dry dock operations. The execution of risk management in floating dry docks under uncertainty could help reduce the damage and effectively control the operators' visible and invisible cost. For those companies, the most important matter is to face up to the tough operating environment in this era of micro-profit (Shang & Tseng, 2010).

In this light, risk identification as regards docking and undocking a vessel in floating dry dock can provide assistance and gain a better understanding of the impact of risks. Secondly, to reduce the frequency and severity of docking and undocking operations under uncertainty due to stability failure will ensure the outcome is reasonable and acceptable for operators. Following the correspondence among experts, and literature presented, a stability failure model of a typical floating dry dock is presented in Figure 7. This hierarchy failure of events presented, firmly considers points at which loss of stability can be prevented notably in undocking a vessel. Short terms of these variable are here mention, while the detailed description of various events that can lead to stability failure in floating dry dock after further brain storming exercise is described in illustrative example where Figure 7 is transformed to its corresponding fault tree for failure modelling.

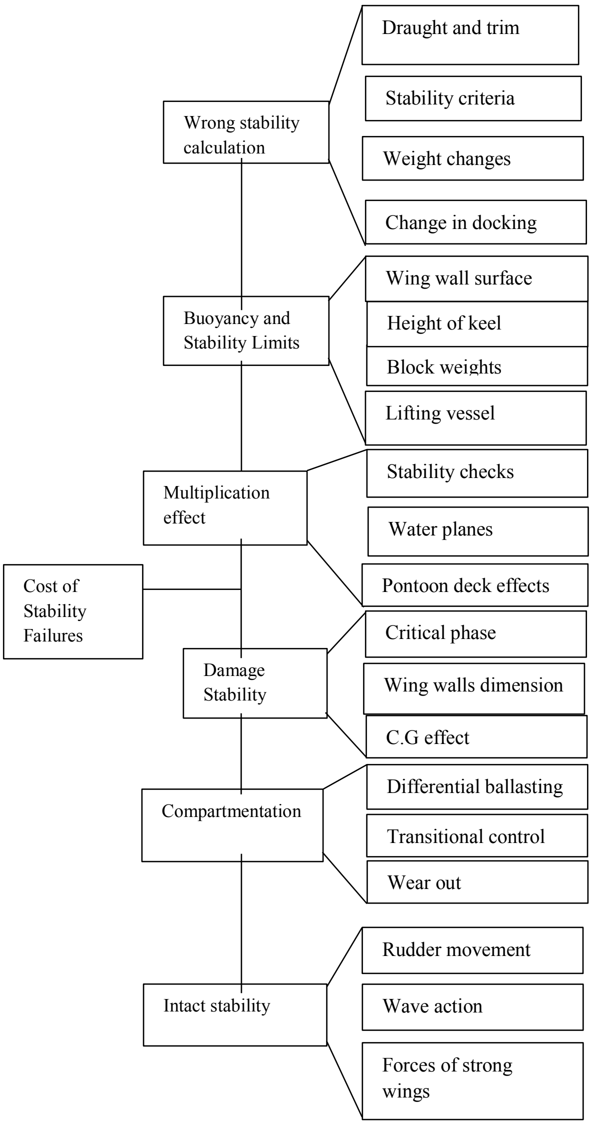


Figure. 7: Floating dock stability failure model

3.9 FAULT TREE IN STABILTY FAILURE

Fault tree in general falls into two categories: coherent and non-coherent. A coherent fault trees is constructed of 'AND' & 'OR' logic operations only, while a non-coherent tree contains other logic operation. This research is mainly concerned with the application of fuzzy evidential reasoning modelling to coherent fault tree analysis (Lui & Chiou, 1997; Adamyan & He, 2003). Fault tree analysis (FTA) of floating dry dock stability failure takes the most unexpected fault event as analysis targets, and then finds all the possible factors which cause the event to occur during docking and undocking a vessel. FTA adopts the corresponding symbol to represent the events, and then connects with the top event (lost due to stability failure), middle events and base events to form an inverse dendriform graph with logic gate symbols (Wu, Xie & Yue, 2010).

In FTA, if some basic events occur at the same time, the top event consequently occurs. Aggregates of the basic events are called 'Cut Sets'. If none of the base events in the cut set occur, the top event does not occur. This cut is called minimum cut set (MCS) (Wu, Xie & Yue, 2010).

Quantitative fault tree requires to be assigned with probability of occurrence and in this study we have to rely on expert judgement. The main objective of this failure model is to aid in grouping risk control measures (RCO) to reduce the frequency of failures and/or mitigate their possible consequences. Once the failure model is welled defined by careful study and variable grouping, then RCO can be effectively understood for better decision making.

4. FUZZY EVIDENTIAL REASONING

Fuzzy evidential reasoning (FER) is a hybrid representation of fuzzy set theory three classes of which discrete fuzzy originates hence the term 'discrete fuzzy evidential reasoning' (DFER). The development of methods for dealing with uncertainty has received considerable attention in the last three decades. Several numerical and symbolic methods have been proposed for handling uncertainty information. An example is a combination of fuzzy (discrete) evidential reasoning.

The induction of knowledge without certainty but only with degrees of belief or credibility regarding a hypothesis has been used in the past to deal with ignorance. A hybrid knowledge representation scheme and inference methodology is desirable to deal with different kinds of uncertainty (Nwaoha, *et al*, 2011). This section provides the academic application of fuzzy (discrete) evidential reasoning approach in maritime risk research.

According to (Godaliyadde *et al*, 2010), a ship hull vibration (SHV) is the most disastrous situation of ship vibration. From the point of view of risk analysis, SHV is addressed as a 'complicated system'. Firstly, the major causes and mechanisms of SHV, constructed in a hierarchical structure and assessment grades given for each criterion.

The quantitative criteria were converted to qualitative ones by employing fuzzy rule based technique and ER. In the qualitative study, SHV is mainly produced by combine action of propellers and machinery. Where propellers (main criteria) had higher amount of possibility (weight) than the machinery and major contributory factors were design, shaft system and propeller cavitation, with small effect of rudder (sub criteria), given a smaller weight factor. The sub criteria for shaft system were torsional, axial and lateral type of vibration patterns and clearance and erosion as causes of rudder failure. The conclusion from the analysis was that the system required safety improvements.

Also, referring to (Wang, Yang & Sen, 1995) the FER approach was applied on the hydraulic hoisting transmission system of a marine crane. The subsystems consist of hydraulic oil tank, auxiliary system, control system, protection and hydraulic servo transmission system. Examples of possible consequences or effects caused by occurrence of the failure modes of these subsystems were presented, where the three precise values of the three variables used to describe safety associated with a failure mode of each subsystem (i.e. the failure likelihood, consequence severity and failure consequence probability) was presented by subjective judgements.

The result obtained in using this approach was that the control system was evaluated to be slightly larger extent as good. Since the safety of the hydraulic transmission system is determined by the safety of each of the constituent subsystem, the safety was evaluated as good to a large extend, as the hierarchical propagation method where there is no use of fault tree. The result provided the design engineer with relevant insight into actions needed to be taken to improve the overall system safety.

In yet another study by (Yang, *et al*, 2005), after the 9/11 terrorist attacks, the lock-out of the American West Ports in 2002 and the breakout of SARS disease in 2003 have further focused the mind of both the public and industrialists to take effective and timely measures for assessing and controlling the risks related to container supply chains.

FER method was used to deal with those threat-based risks, which were more ubiquitous and uncertain than the hazard-based risks in the chains. Its feasibility was validated by a case study associated with a threat of terrorist attacking ports. This subjective risk analysis approach of container supply chains used FER as a realistic way to cope with imprecision by using linguistic assessments.

However, it was suggested that linguistics descriptions define risk assessment parameters to a discrete extent so that they can at times be inadequate. In this study, it was important to synthesise the risk evaluated of the components in a rational way to obtain the risk evaluation of the subsystems and the whole system. The purpose of this work was supported by creating four parameters to assess threat-based risks; applies a FTA method to construct a hierarchical structure as to enable the application of the ER approach in the realm of supply chains; and validate its feasibility by a case study of terrorist attacking ports.

The main novelty of this work was a proposed four parameters to carry out threat-based risk estimation. They were '*Will*', '*Damage capability'*, '*Recall difficulty'*, and '*Damage probability'*. In this study, the 'Will' decides the failure likelihood. The combination of '*Damage capability'* and '*Recall difficulty'* responds to the consequence severity of the threat-based risk. The '*Damage probability*' represents the failure consequence probability of the risk.

The linguistic variables that are used to describe the probability of the four parameters can be characterised by their fuzzy set membership functions to a set of categories which describes their respective degrees. Later the best fit method was used to obtain the description 'S' of a threat judged by assessor mapped into one (or all) of the defined safety expression. In their case study, six basic events were identified and the fault tree, the basic events can be ranked in terms of their risk levels using the fuzzy set approach. The safety level in this study was assessed to be *'Good'* to some percentile extent.

Lastly, according to (Nwaoha, *et al*, 2011), an illustrative application of FER to failure modes modelling uncertainty treatment of a LNG spherical (Moss) tank design seemed feasible. The first part of the study included hazard identification process using brainstorming technique on various causes of events in LNG moss design tankers using fault tree analysis diagram.

The second part of the illustration was risk assessment, and associated risks associated with the failure modes were assessed. This is the most detailed part which includes gathering subjective language from experts on the three risk parameters in the study and FER mathematics applied to obtain crisp values of risk of each base event. Twelve (12) based events were identified and overall safety expression of top event estimated to be 'poor'. This implies that the three risk control options, regular inspection, training of crew, and effective maintenance needed to be re-enforced to improve safety.

In conclusion, FER was proven once more as an outstanding method for an effective risk estimation and control of hazards in marine engineering structures using discrete fuzzy set manipulation formula and evidential reasoning in applications where there is lack of data. The next section presents the mathematics of FER.

5. THE MATHEMATICS OF DFER

The methodology is constructed based on a generic evidential reasoning incorporated with the method of discrete fuzzy risk analysis. Although this system development methodology is developed for floating dry docks, other researchers can easily follow as guide to design and develop other discrete fuzzy evidential reasoning approach in other dry docks or other applications.

5.1 DISCRETE FUZZY SET MATHEMATICS

The fuzzy philosophy states that everything is a matter of degree. A world of multivalence and the opposite of which is bivalence. Positivism demands evidence, factual or mathematical. Based on binary logic it comes down to law; *A* or not-*A*- it cannot be both *A* and not –*A* (Yang, *et al*, 2005).

Fuzzy logic is reasoning with fuzzy sets. A fuzzy cognitive map is a fuzzy casual picture of the world and a fuzzy system is a set of fuzzy rules that converts inputs into output. Fuzzy is a mathematical formalization which enables representation of degrees of membership of members in sets (Fellows & Liu, 2008). The fuzzy approach offers alternatives to positivism (Kosko, 1984; Zadeh, 1965; Zimmerman, 2001).

The real applications are not as simple; sometimes an understanding of mathematics is required. The applications of fuzzy theory to economics, the social science, management, psychology and other areas have been published so far. In these applications there are some common approaches in uncertain environments, fuzzy modelling, and uncertain structure identification and decision making which is a topic in operations and research (Mukaidono, 2001).

There are various techniques of fuzzy logic such as '*discrete'* [Godaliyadde, et al, 2010; Wang, Yang & Sen, 1995; Yang, *et al*, 2005) '*continuous fuzzy sets'* (Kao, *et al*, 2007; Ung, *et al*, 2006; Pillay & Wang, 2001) and '*fuzzy rule base'* (Yang *et al*, 2006; Kowalewski, Podsiadlo & Tarelko, 2007) that have been used in risk assessment in the maritime industry. According to (Nwaoha, *et, al*, 2011) the '*discrete fuzzy set' is preferred* due to its simplification. To assess the fuzzy safety associated with a basic event, it is required to synthesize the associated *failure likelihood*, *consequence severity* and *failure consequence probability*. The fuzzy set manipulation used in risk assessment is (Nwaoha, *et al*, 2011):

$$S_i = C^s \circ F^{CP} \times F^L \quad (1)$$

S_i Risk/safety score of the i^{th} event
F^{CP} Failure consequence probability
F^L Failure likelihood probability
o Fuzzy composition operation
x Fuzzy cartesian product operation
C^s Consequence severity

This is represented in term of membership functions μ, as follows

$$S_{i\mu} = C^s_\mu \circ F^{CP}_\mu \times F^L_\mu \quad (2)$$

Expressing linguistic parameters in terms of membership functions,

C^s_μ is description function of C^s in terms of the membership degree of μ (1, 2, 3, 4, 5, 6, 7) associated categories in Table 1.

F^{CP}_μ is description function of F^{CP} in terms of the membership degree of μ (1, 2, 3, 4, 5, 6, 7) associated categories in Table 2.

F^L_μ is description function of F^L in terms of the membership degree of μ (1, 2, 3, 4, 5, 6, 7) associated categories in Table 3.

$S_{i\mu}$ means description function of S_i in terms of the membership degree μ (1, 2, 3, 4, 5, 6, 7) associated categories in Table 4 obtained using a max-min method based on equation 2.

Table 1: Consequence Severity

F	Definition	Linguistic Variable Membership sets Category C^s_μ						
		1	***2***	***3***	***4***	***5***	***6***	***7***
N	Minor injury or unscheduled docking required	1	0.75	0	0	0	0	0
MA	Multiple injury, operations interrupted marginally	0	0.25	1	0.75	0	0	0
MO	Multiple injury, operation and production interrupted	0	0	0.75	0.25	0.25	0	0
CR	Single dead, high degree of operational interruption	0	0	0	0.75	1	0.25	0
CT	Multiple deaths, total system loss	0	0	0	0	0	0.75	1

Table 2: Failure Consequence Probability

F	Definition	Linguistic Variable Membership sets Category F^{CP}_{μ} 1	2	3	4	5	6	7
HU	HU given occurrence of failure event (extremely unlikely to exist	0	0	0	0	0	0.75	1
U	U but possible given occurrence that the failure event happens	0.25	1	0.75	0	0	0	0
RU	RU given the occurrence of failure event	0	0.25	1	0.75	0	0	0
L	L given that failure event occurs and no detection.	0	0	0.5	1	0.5	0	0
RL	RL given occurrence failure event from time to time due to operational weaknesses or design weakness	0	0	0	0.75	1	0.25	0
HL	HL given occurrence of failure event due to highly likely potential hazardous situation	0	0	0	0	0.75	1	0.25
D	Possible consequence given the occurrence of a failure event repeated during operations due to an anticipated potential design and operations procedure draw back	0	0	0	0	0	0.75	1

Table 3: Failure likelihood

F	Definition	PSY	Linguistic Variable Membership sets Category F^{L}_{μ} 1	2	3	4	5	6	7
VL	Likely to occur once per year in the floating dry dock	$0.1<E$	1	0.75	0	0	0	0	0
L	Likely to occur once in the life in all the floating dry dock	$0.01<E<0.1$	0.25	1	0.75	0	0	0	0
RL	Likely to occur 10 times per year in floating dry dock	$0.1^{-2}<E<0.1^{-1}$	0	0	0.25	1	0.75	0	0
A	Likely to occur once per year for all floating dry docks	$0.1^{-3}<E<0.1^{-2}$	0	0	0.5	1	0.5	0	0
RF	Likely to occur once times in 10 years for all floating dry dock	$0.1^{-4}<E<0.1^{-3}$	0	0	0	0.75	1	0.25	0
F	Repeated failure	$E= 0.25^{-1}$	0	0	0	0	0.75	1	0.25
HF	Failure is almost inevitable	$E> 0.25^{-1}$	0	0	0	0	0	0.75	1

Table 4: Safety membership

$S_{i\mu}$	Categories						
	1	2	3	4	5	6	7
P	0	0	0	0	0	0.75	1
A	0	0	0	0.5	1	0.25	0
G	0	0.25	1	0.5	0	0	0
E	1	0.75	0	0	0	0	0

Consequence severity describes the magnitude of possible consequences, which is ranked according to severity of the failure effects. Its variables describes in Table 1 as negligible (N), marginal (MA), moderate (MO), critical (CR) and catastrophic (CT).

Failure consequence probability is the probability that ensued consequences gives the occurrence of the event where the linguistics terms describe in Table 2 are highly unlikely (HU), unlikely (U), reasonably unlikely (RU), likely (L), reasonably likely (RL), and definite (D).

Failure likelihood describes the failures frequencies in a certain time, which directly represents the numbers of failures anticipated during the design life span of a particular system or an item. Linguistic variables for Table 3 are defined thus: Very Low (VL), low (L), Reasonably Low (RL), Reasonably Frequent (RF), frequent (F) and Highly frequent (HF), per shipyard year (PYS) and definite variable (*E*). Table 4 describes the membership expression as poor (P), average (AV), good (G) and excellent (E).

In better understanding membership expression for Poor in Table 4, P [0, 0, 0, 0, 0, 0, 0.75, 1] with a more expressive failure likelihood VL [1, 0.75, 0, 0, 0, 0, 0, 0, 0] in Table 3 the safety expressions Poor can be incorporated into safety score. Given a membership expression of [‘1’/1, ‘2’/0.75, ‘3’/0, ‘4’/0, ‘5’/0, ‘6’/0, ‘7’/0]. In this light the safety expression for safety poor (S_{ip}) is expressed;

$$Sip = C^{s}_{CT} \text{ o } F^{CP}_{D} \times F^{L}_{HF} \quad (3)$$

The safety expression for average, good and excellent is likewise expressed. Using the Best-Fit method, the safety risk description S_i of the i^{th} basic event can be mapped back to one (or all) of the defined four safety expression in this study (Nwaoha, *et al*, 2011; Wang, Yang & Sen, 1995).

The method uses the distance between S_i and each of the safety expressions to represent the degree to which S_i is confirmed to each of them. An illustration is given when using safety expression poor,

$$D_{i1}(S_i, \text{poor}) = \left[\sum_{j=1}^{7}\left(\mu^{j}_{S\,i} - \mu^{j}_{poor}\right)^2\right]^{1/2} \quad (4)$$

When the unscaled distance D_{iJ} (j=1, 2, 3, 4) is equal to zero, S_i is just the same as the j^{th} safety expression in terms of membership functions. In such a case, S_i should not be evaluated to other expressions (Godaliyadde, *et al*, 2010). Because of this D_{iJ} (1<J<4) is introduced and defined based on D_{ij} for any given distances for S_i is used to calculate α_{ij}. In order to more clearly express the safety level of S_i the reciprocals of the relative distances between S_i and each safety expression, D_{ij}, expressed as α_{ij} are normalized into new indexes β_{ij} (j=1,2,3,4). α_{ij} can be defined as

$$\alpha_{ij} = 1/ D_{ij}/ D_{iJ} \quad j = 1, 2, 3, 4 \quad (5)$$

If D_{ij} is equal to zero, it follows that β_{ij} is equal to 1 and the others are equal to 0. In other situations, β_{ij} can be expressed as

$$\beta_{ij} = \alpha_{ij}/\textstyle\sum_{m=1}^{4} \alpha_{ij} \; j= 1,2,3,4 \quad (6)$$

Each β_{ij} (j=1,2,3,4) represents the extent to which S_i belongs to j^{th} defined safety expression. Mapping back to safety expression output (SO) implies;

$$SO(S_i) = [(\beta_{i1}, \text{‘P’}), (\beta_{i2}, \text{‘AV’}), (\beta_{i3}, \text{‘G’}), (\beta_{i4}, \text{‘E’}) \quad (7)$$

5.2 ER MATHEMATICS

Once the safety output is obtain from basic event, using equation six (6) and expressed in its corresponding safety expression output (SO), then it is important to access a situation where two multi-national experts are involved. This section seeks first to establish the mathematics of using ER using two experts where there is no software. In this study care is given on how equation fifteen (15) is derived. Where more than three experts are involved the software is required to be used, nonetheless the safety expression aggregated can be transformed to its crisps value.

The mechanism of ER can be explained using the aggregation of two safety assessments. Suppose the two safety assessments are denoted β^{j}_{Sij} is expressed thus (Nwaoha, *et al*, 2011): β^{j}_{Si1} and β^{j}_{Si2} (j = 1, 2, 3, 4) represents the extent to which the safety assessments of two basic events, S_{i1} and S_{i2} are confirmed to j^{th} safety expression. Suppose the relative weights for SO (S_{i1}) and SO (S_{i2}) are w_1 and w_2.

The relative weights of SO (S_{i1}) and SO (S_{i2}) are normalized using the expression as follows

$\sum_{k=1}^{2} w_k = 1: 0 \leq w_K \geq 1$ (8)

For SO (S_{i1}) and SO (S_{i2}), their probability masses S_{i1m} and S_{i2m} are expressed as follows $S_{i1m} = w_1 \beta^j_{Si1}$ and $S_{i2m} = w_2 \beta^j_{Si2}$, m = 1, 2, 3, 4. Meanwhile the following can be obtained $S^{\wedge}_{i1H} = 1 - w_1 = w_2$ and $S^{\wedge}_{i2H} = 1 - w_2 = w_1$

$$S^{\varphi}_{i1H} = w_1\left(1-\sum_{k=1}^{2} \beta^j_{Si1}\right) = w_1 [1-(\beta^1_{Si1}+ \beta^2_{Si1}+ \beta^3_{Si1}+ \beta^4_{Si1})]$$

$$S^{\varphi}_{i2H} = w_2\left(1-\sum_{k=1}^{2} \beta^j_{Si1}\right) = w_2 [1-(\beta^1_{Si2}+ \beta^2_{Si2}+ \beta^3_{Si2}+ \beta^4_{Si2})] \quad (9)$$

S^{φ}_{i1H} and S^{φ}_{i2H} represent the degree to which other basic events can play a role in the assessment. $S^{\wedge}_{i1H}$ and $S^{\wedge}_{i2H}$ are the individual remaining belief values unassigned for SO (S_{i1}) and SO (S_{i2}) respectively. $S_{i1H} = S^{\wedge}_{i1H} + S^{\varphi}_{i1H}$ and $S_{i2H} = S^{\wedge}_{i2H} + S^{\varphi}_{i2H}$ where S_{i1H} and S_{i2H} represent possible incompleteness in the subsets SO (S_{i1}) and SO (S_{i2}). The combine probability masses, S_{i1m} and S_{i2m}, and S_{i1H} and S_{i2H} are as follows

$$S_{im} = K (S_{i1m}S_{i2m} + S_{i1m}S_{i2H} + S_{i2m}S_{i1H}) \quad (10)$$

$$S_{iH} = K (S_{i1H} S_{i2H}), \quad m = 1, 2, 3, 4 \quad (11)$$

$$K= 1- \left[\sum_{T=1}^{4} \sum_{R=1}^{4} S_{iA}S_{i2B}\right]^{-1} \quad (12)$$

The combined degree of belief (T^m) can be calculated as follows;

$$T^m = S_{im}/(1- S_{iH}), \quad m = 1, 2, 3, 4, \quad (13)$$

To rank the 'very high' risk hazards, the crisp values of their safety descriptions can be calculated as follows:

$$Q_i = \sum_{m=1}^{4} T^m \times P^m \quad (14)$$

$P_1 = P^1_4/ P^1_1$, $P_2 = P^1_3/ P^1_1$, $P_3 = P^1_2/ P^1_1$, $P_4 = 1$

P^1_1, P^1_2, P^1_3, P^1_4 represent the unscaled numerical values associated with the linguistic terms (i.e. poor, average, good and excellent) of the safety expression. P^1_1, P^1_2, P^1_3, P^1_4 can be calculated as follows ((Nwaoha, *et al*, 2011):

P^1_1 = [0.75/(0.75+1)]6 + [1/(0.75+1)]7 = 6.571

P^1_2 = [0.5/ (0.5+1+0.25)]4 + [1/0.5+1+0.25]5 + [0.25/(0.5+1+0.25)]6 = 4.854

P^1_3 = [0.25/0.25+1+0.5]2 + [1/0.25+1+0.5]3 + [0.5/(0.25+1+0.5)]3 + [0.5/(0.25 + 1 + 0.5)]4 = 3.141

P^1_4 = [1/1(1+0.75)]1 + [0.75/(1+0.75)]2 = 1.428

Substituting the values of P^1_1, P^1_2, P^1_3, and P^1_4 in equation 14 yields:

$$Q_i = 0.271 \times T^1_i + 0.478 \times T^2_i + 0.739 \times T^3_i + 1.0 \times T^4_i \quad (15)$$

6. FER FRAMEWORK

In understanding the system under review, it is imperative to identify relevant literature pertaining to risk and understand the mathematics of the framework. Once this has been established as seen in previous sections, it is left to the discretion of the risk analyst to contact corresponding experts with knowledge on subject matter or area of case under review.

It is also important to purchase or identify the respective computer software required for the analysis. Once confident of the above information, this section presents a logical framework in applying discrete fuzzy evidential reasoning (DFER) for assessing risk in docking and undocking a vessel for repairs.

The purpose of this study is to design and develop a DFER framework to assist docking and undocking operators and managers in identifying potential risk factors and evaluating the corresponding dock development risks. DFER is constructed following the five-stage system development methodology which is based on a generic fuzzy decision support system (Power, 1999) methodology incorporated with a method of evidential reasoning.

Although this system development methodology is develop to support decision making, it is believe that other researchers can easily follow as a guideline to design and develop other frameworks. The system development process consists of five stages, namely the construction of fuzzy evidential risk analysis model, development of system, analyse and re-design the system, and evaluating the system. An overview of these five stages of system development.

First, a fuzzy risk analysis model is constructed as the kernel of the system. Second, system risk control measure architecture was developed. Third, system design and analysis was carried out in modularity with re-defining functionalities of the system components and to improve our understanding of how they interact with one. Fourth the system is evaluated in order to learn more about the concepts, framework, and design through the system-building process. A detailed description of the first stage (major stage) is given here.

The major stage of this framework is to construct a fuzzy risk analysis model for the system understudy and to provide an appropriate method for discrete fuzzy analysis method. In this framework the risk analysis is first developed in a hierarchy order to identify variables and then transferred to a corresponding fault tree.

Fault tree requires numerical values not readily available however the information that is related to most uncertainty factors is not numerical. Discrete fuzzy set theory provides an approximate model for the evaluation of the risk faced by docking and undocking a vessel through a linguistic approach (Nwaoha, et al, 2011; Godaliyadde, et al, 2010; Wang, Yang & Sen, 1995). The procedure for fuzzy risk analysis is presented in Figure 8.

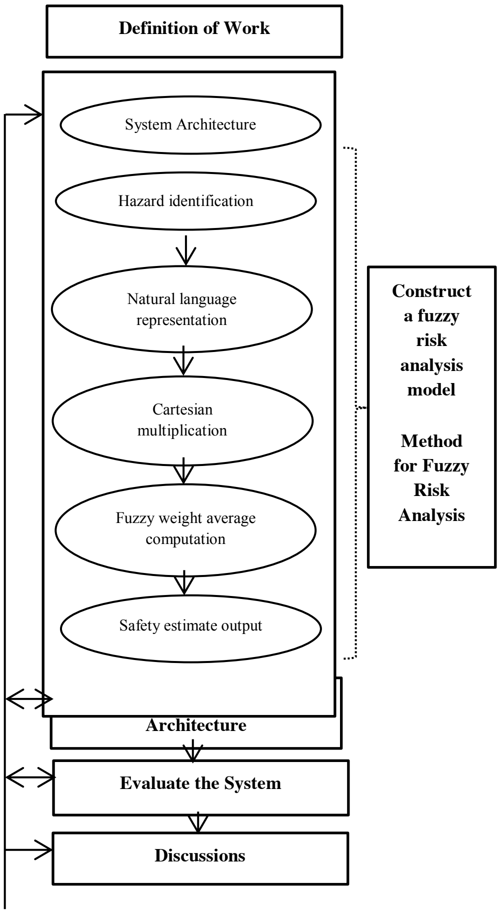


Figure. 8: DFER development methodology framework

The experts participating in the study provide natural language representation for failure consequence probability, consequence severity and probability of consequence of each base event and the resulting safety output of each expert is carried out by hand calculation using equation one (1) to seven (7) presented in section 5. The last part of this major stage is to aggregate the safety output computed for all the experts using the evidential reasoning software, where the weights of each expert are assigned by risk analyst.

The result of the overall input of the middle event in the fault is run in fault tree software to get the overall failure rate of the top event. This stage consists of five steps: risk identification, fuzzy assessment, expert weight assessment, safety aggregation output of each middle event, and numerical approximation of top event of failure.

6.1 DEFINITION OF WORK

In the floating dry dock several hazards include, collision, fire, fall from height, failure of pontoon, sinking due to stability failure etc. Various scenarios can lead to stability failures and this depends on size of floating dock, size of the vessel to be dock and its condition. Experts required in identification model must consider the sea states, and other weather conditions.

6.2 DEVELOP SYSTEM ARCHITECTURE

Good system architecture provides a road map for the system building process by placing components into perspectives, defining their functionalities, and demonstrating how they will interact with one another. Floating dry dock is a centre of activity in ship repair and developing a DFER. The literature for stability failure was reviewed to include; stability calculations, buoyancy and stability, multiplication effect, damage stability, compartmentation and intact stability as middle events M1, M2, M3, M4, M5, and M6 respectively. The corresponding base events as seen in and translated to fault tree consists of twenty (20) base events B1 to B20.

6.3 NATURAL LANGUAGE

According to (Karwowski & Mital, 1986), traditional approaches to risk assessment obtain their overall risk scores by calculating the product of exposure likelihood, and the consequences of a possible accident due to the hazard. A simpler approach that is advocated by some risk experts is to multiply the severity of consequences by the likelihood of their occurrence, as the likelihood of the occurrence automatically includes exposure (Waring & Glendon, 1998).

Also, according to (Boehm, 1989), risk impact is defined as the product of the probability of an unsatisfactory outcome (likelihood) and the loss of to the parties affected when the outcome is unsatisfactory (severity). Consequently, two linguistic variables, Likelihood, and Severity are the first part defined to calculate the overall risk.

A third variable mentioned by (Nwaoha, *et al*, 2011), is the failure consequence probability added as a catersian product to calculate the overall risk. In this study, the membership functions of the linguistic terms are characterised by discrete numbers, as these are very often used in maritime environment and in managerial decision making.

6.4 ASSESSMENT AGGREGATION

In this stage, an aggregate of several evaluators' fuzzy assessment is performed by using the evidential reasoning method. By allowing more than one expert (evaluator) to assess the risks associated with docking a vessel in a floating dry dock, a more objective and unbiased result can be obtained. The evidential reasoning method is used to obtain the mean of the expert's opinion.

The formula and equation fifteen (15) derived in section 5 is when two experts are concern. Where three or more experts consulted software is used to obtain the safety expression of the system. The value Q_i is then used to obtain the overall safety of the basic event as appropriate.

6.5 ANALYSE AND DESIGN THE SYSTEM

Analysis and design are important aspects of the floating dry dock system development process in regards to stability. Design involves an understanding of the domain being studied, the application of various alternatives, and the synthesis and evaluation of proposed solutions. Design specifications are used as a blueprint for the implementation of the system. The determination of system components and developmental platform is made during this phase. Stability failure model consisting of six interrelated components identified as middle events.

6.6 EVALUATE THE SYSTEM

Once the system is developed, then testing and evaluation of the model can be performed. Through system evaluation, information can be captured on what the system does and do not do to meet their system requirements. First testing and evaluation of the system were performed. All the middle events were tested for accuracy and completeness, and the outputs generated were checked and validated. These tests ensured that the system was performing functions that would meet the requirements of docking vessels. Secondly, once the failure model was developed, outcome evaluation is conducted in two phases.

The first phase was domain expert evaluation, and the second phase is potential user evaluation. The approach used in this study is measure of the effectiveness of the control system. Through measuring the effectiveness of risk control measures, we can see the ability of the system to accomplish its objectives or mission. Items to measure the usability of the dry dock system reflect the usefulness and ease of docking operation.

6.6 (a) Expert Evaluation

Evaluation by domain experts helps to determine the accuracy of embedded knowledge. The floating dry dock failure due to stability model was validated by a group of 5 participants attending the dry docking conference. The failure model was demonstrated and an evaluation form was distributed to the experts who presented papers in the fuzzy modelling session of the meeting. All experts were routine floating dry dock operators with an average of more than 10 years working experience and good knowledge of stability concerns within this industry. They were asked to evaluate the model from two perspectives; effectiveness of the system, most respondents agreed that the system was an effective risk assessment model; in particularly indicating that it can assist in assessing risks associated the stability failure in floating dry docks.

6.6 (b) User Evaluation

Evaluations by users help to determine the utility of a system according to the following criteria: ease of interaction, the extent of its capabilities, its efficiency and speed, its reliability and whether it produces useful results. The evaluation form was transformed electronically and a total of 10 e-mails were sent randomly from selected sample mailing list of possible floating dry dock design consultancy. Effectiveness of the system can be classified as follows: (1) Assist in assessing risk associated with floating dry dock stability failure; (2) Provide an effective mean to collect, store and analyse perception on potential risk and; (3) Monitor and mitigate risk. Another criteria is utility of the system to perform; (4) Learning to operate the system would be easy for me;(5) My interactions with the system would clear and understandable; (6) I find the system to be flexible to interact with: (7) the system’s variables are self-explained and easy to understand; (8) I find the system easy to use; (9) The system is user friendly; (10) Likely to recommend to other users.

7. ILLUSTRATIVE CASE STUDY

7.1 DEFINE WORK

For this study, the events leading to stability failure of a floating dry dock is assessed. The aim is to provide knowledgeable risk control options for decision making through respondents from expert asked about the probability of occurrence, degree of loss, and consequence probability of failure for each risk item.

7.2 CHOOSE GOALS & SET CONSTRAINTS

Once work is defined, the next step is to set goals and identify participating shipyard industries to include a multinational correspondence. The various databases and consulting experts within the speciality of floating dry dock design, construction and operation identified.

In this study, this floating dry dock is said to be operating in an unstable and shallow ship repairing region, where waves and wind actions are taken into further consideration. A typical manual extensive study for understanding stability failure is the dry docking manual by Hedger Dry Dock, USA. The risk analyst is herein trained appropriate to the understanding and application of FTA, FER and the stability failure model.

7.3 HAZID IDENTIFICATION

The 20 risk items were selected through interviews with ship repairing industry experts. The panel of experts consisted of experts working in ship repairing industry company (1 design, 1 dry dock manager, 1 production manager) and experts working in related industry (1 classification, and 1 dry docking conference organiser). The selected risk categories and 20 base events of risk items are shown in Table 5. The use of resourced literature presented in section 3 and brain storming technique was used to confirm expert risk identified with stability failure of a floating dry dock. The middle events include: stability error calculation error (M1), buoyancy and stability strength error (2), multiplication effects (M3), inappropriate intact stability study (M4), damage stability failure (M5), and compartmentation (M6). The various base events associated with these middle events are described in Table 5. Furthermore, the failure modes of floating dry dock due to stability are transferred to its corresponding FTA diagram in order to estimate their safety/risk levels. The symbols of the gates are illustrated in Figure 9 guided by expert assistance.

Table 5: Variable Description

Base Event	Definition	Description
B1	Draught and trim	Failure to closely monitor draughts and trim factors by dry dock master
B2	Stability criteria	Failure to check criteria being put in stability calculation
B3	Weight changes	Inadequate noting of changes in weight during undocking of vessel
B4	Change in docking	Failure to recalculate new stability characteristics when any changes occurred.
B5	Wing wall surface	Increased wing wall surface in minimum stability phase
B6	Height of keel	Failure to incorporate height of keel in stability limit checks
B7	Block weights	Failure to note total weight distribution on the blocks
B8	Lifting vessel	Failure to provide sufficient stability at each phase of lifting a vessel
B9	Stability checks	Change in dock stability characteristics
B10	Water planes	Effects of large water plane of pontoon deck
B11	Pontoon deck effects	Lower or negative GM ratio before pontoon deck submerges
B12	Critical phase	Inappropriate knowledge of critical phase of intact stability
B13	Wing walls dimension	In appropriate wing walls dimensions
B14	C.G effect	Unexpected shift of centre of gravity towards one side of the dock
B15	Differential ballasting	Inappropriate docking differential ballasting
B15	Transitional control	Inappropriate undocking transitional control
B17	Wear out	Compartment wear out
B18	Rudder movement	Excessive rudder movement
B19	Wave action	Increase wave action generating roll motion
B20	Strong wings	Forces of strong wings

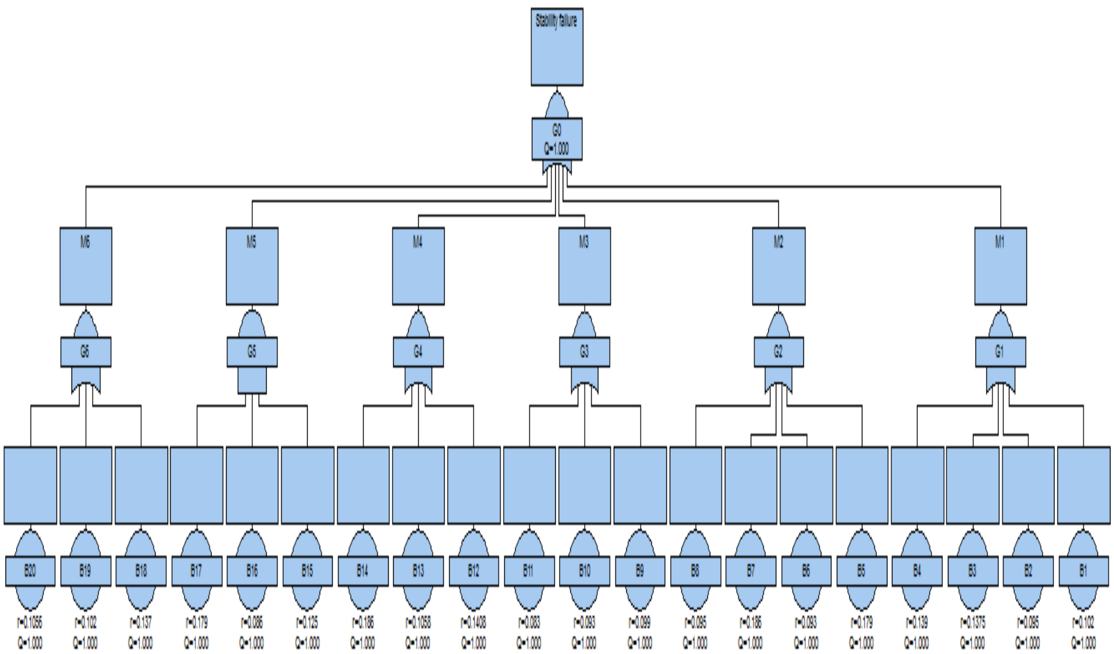


Figure. 9: FTA for floating dock stability failure

Table 6: Expert Language for Middle Event M1

E/B	**B 1**	**B 2**	**B 3**	**B 4**
E1	$F^{L}_{RL}F^{CP}_{U}C^{S}_{MA}$	$F^{L}_{RL}F^{CP}_{RU}C^{S}_{N}$	$F^{L}_{RF}F^{CP}_{L}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{L}C^{S}_{MA}$
E2	$F^{L}_{RL}F^{CP}_{D}C^{S}_{MO}$	$F^{L}_{L}F^{CP}_{RU}C^{S}_{M}$	$F^{L}_{AV}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{RL}F^{CP}_{L}C^{S}_{CT}$
E3	$F^{L}_{L}F^{CP}_{D}C^{S}_{MA}$	$F^{L}_{L}F^{CP}_{HU}C^{S}_{N}$	$F^{L}_{RL}F^{CP}_{RU}C^{S}_{M}$	$F^{L}_{RF}F^{CP}_{HU}C^{S}_{MO}$
E4	$F^{L}_{AV}F^{CP}_{RU}C^{S}_{CR}$	$F^{L}_{L}F^{CP}_{RU}C^{S}_{MO}$	$F^{L}_{RL}F^{CP}_{U}C^{S}_{MO}$	$F^{L}_{RF}F^{CP}_{HU}C^{S}_{MO}$
E5	$F^{L}_{RF}F^{CP}_{HU}C^{S}_{M}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{MA}$	$F^{L}_{L}F^{CP}_{RU}C^{S}_{MO}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{CT}$
S O	*S*1	S 2	S 3	S 4

Table 7: Expert Language for Middle Event M2

E/B	**B 5**	**B 6**	**B 7**	**B 8**
E1	$F^{L}_{RF}F^{CP}_{RL}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{M}$	$F^{L}_{VL}F^{CP}_{HF}C^{S}_{M}$	$F^{L}_{RL}F^{CP}_{RU}C^{S}_{N}$
E2	$F^{L}_{AV}F^{CP}_{HL}C^{S}_{M}$	$F^{L}_{AV}F^{CP}_{RU}C^{S}_{CT}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{L}F^{CP}_{RU}C^{S}_{M}$
E3	$F^{L}_{F}F^{CP}_{HL}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{M}$	$F^{L}_{AV}F^{CP}_{D}C^{S}_{N}$	$F^{L}_{L}F^{CP}_{HU}C^{S}_{N}$
E4	$F^{L}_{AV}F^{CP}_{HL}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{L}C^{S}_{CT}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{L}F^{CP}_{RU}C^{S}_{MO}$
E5	$F^{L}_{HF}F^{CP}_{D}C^{S}_{CR}$	$F^{L}_{VL}F^{CP}_{L}C^{S}_{CT}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{MA}$
S O	S5 = S17	S 6 = S10	S 7 = S14	S 8 = S2

Output **S aggregation** using ER to obtain middle

Table 8: Expert Language for Middle Event M3

E/B	**B 9**	**B 10**	**B 11**
E1	$F^{L}_{L}F^{CP}_{HF}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{HL}C^{S}_{CT}$
E2	$F^{L}_{RL}F^{CP}_{U}C^{S}_{MA}$	$F^{L}_{AV}F^{CP}_{RU}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{U}C^{S}_{M}$
E3	$F^{L}_{L}F^{CP}_{D}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{D}C^{S}_{CT}$
E4	$F^{L}_{L}F^{CP}_{U}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{L}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{RU}C^{S}_{CT}$
E5	$F^{L}_{L}F^{CP}_{U}C^{S}_{CT}$	$F^{L}_{VL}F^{CP}_{L}C^{S}_{CT}$	$F^{L}_{AV}F^{CP}_{RL}C^{S}_{M}$
S O	S9	S 10	S 11

Table 9: Expert Language for Middle Event M4

E/B	**B 12**	**B 13**	**B 14**
E1	$F^{L}_{AV}F^{CP}_{RU}C^{S}_{M}$	$F^{L}_{RL}F^{CP}_{RL}C^{S}_{CT}$	$F^{L}_{VL}F^{CP}_{HF}C^{S}_{M}$
E2	$F^{L}_{AV}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$
E3	$F^{L}_{RL}F^{CP}_{L}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{CT}$	$F^{L}_{AV}F^{CP}_{D}C^{S}_{N}$
E4	$F^{L}_{L}F^{CP}_{L}C^{S}_{M}$	$F^{L}_{RF}F^{CP}_{RL}C^{S}_{CT}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$
E5	$F^{L}_{AV}F^{CP}_{RU}C^{S}_{M}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$
S O	S12	S 13	S 14

Table 10: Expert Language for Middle Event M5

E/B	**B 15**	**B 16**	**B 17**
E1	$F^{L}_{L}F^{CP}_{HL}C^{S}_{CT}$	$F^{L}_{L}F^{CP}_{L}C^{S}_{MA}$	$F^{L}_{RF}F^{CP}_{RL}C^{S}_{M}$
E2	$F^{L}_{L}F^{CP}_{U}C^{S}_{M}$	$F^{L}_{RL}F^{CP}_{L}C^{S}_{CT}$	$F^{L}_{AV}F^{CP}_{HL}C^{S}_{M}$
E3	$F^{L}_{L}F^{CP}_{D}C^{S}_{CT}$	$F^{L}_{RF}F^{CP}_{HU}C^{S}_{MO}$	$F^{L}_{F}F^{CP}_{HL}C^{S}_{CT}$
E4	$F^{L}_{L}F^{CP}_{RU}C^{S}_{CT}$	$F^{L}_{RF}F^{CP}_{HU}C^{S}_{MO}$	$F^{L}_{AV}F^{CP}_{HL}C^{S}_{M}$
E5	$F^{L}_{AV}F^{CP}_{RL}C^{S}_{M}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{CT}$	$F^{L}_{HF}F^{CP}_{D}C^{S}_{CR}$
S O	S15 = S11	S 16 = S4	S 17

Table 11: Expert Language for Middle Event M6

E/B	**B 18**	**B 19**	**B 20**
E1	$F^{L}_{RF}F^{CP}_{L}C^{S}_{M}$	$F^{L}_{RL}F^{CP}_{U}C^{S}_{MA}$	$F^{L}_{RL}F^{CP}_{RL}C^{S}_{CT}$
E2	$F^{L}_{AV}F^{CP}_{U}C^{S}_{N}$	$F^{L}_{RL}F^{CP}_{D}C^{S}_{MO}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$
E3	$F^{L}_{RL}F^{CP}_{RU}C^{S}_{MO}$	$F^{L}_{L}F^{CP}_{D}C^{S}_{MA}$	$F^{L}_{L}F^{CP}_{RL}C^{S}_{CT}$
E4	$F^{L}_{RL}F^{CP}_{U}C^{S}_{MO}$	$F^{L}_{AV}F^{CP}_{RU}C^{S}_{CR}$	$F^{L}_{RF}F^{CP}_{RL}C^{S}_{CT}$
E5	$F^{L}_{L}F^{CP}_{RU}C^{S}_{MO}$	$F^{L}_{RF}F^{CP}_{HU}C^{S}_{MO}$	$F^{L}_{RF}F^{CP}_{U}C^{S}_{N}$
S O	S18 = S3	S 19 = S1	S 20 = S13

7.4 RISK ASSESSMENT

Five experts presented in Table 6 to 11, provide the base events parameter for each middle event M1 to M6.

FTA is constructed for 20 identified hazards from data collected. This step, is quite tedious, but fault tree graphical representation, makes sure nothing is missing during analysis. The natural language is defined in Table 6-11 and each expert provides weight of base events based on three parameter. In this section, this system is examined to demonstrate the proposed methodology incorporating fuzzy (discrete) set modelling and evidential reasoning. Risk assessment is carried out on a hazard (floating dry dock system failure) based on the available information. The risks associated with failure modes of the floating dry dock system failure due to stability are assessed through proposed approach.

The fuzzy (discrete) set theory is used to investigate the safety/risk level of hazard because of existence of uncertainty of failure data, while ER is used to synthesize all the risk levels of the failure modes that lead to the occurrence of the hazard.

In understanding the application of this method middle event M1 is used, with four base events B1, B2, B3, and B4. For each base events, five safety experts as presented in Table 6 state how this base event can lead to failure of middle event M1. Each expert was to give its knowledge on each of the parameters i.e. failure likelihood (F^L), failure consequence likelihood (F^{CL}), and consequence severity (C^S). Once a linguistic term was identified the membership function for example failure likelihood (e.g. VL, L, AV, L, HL), where HL refers to [0, 0, 0, 0, 0.75, 1, 0.25].

Using base event, B1, the safety expression S_1^1, means experts 1 (superscript) and base event 1(subscript), base event B1, and expert 1, is used for illustration, where $F^{CP}_{HL} =$ means failure consequence probability is Highly Likely and membership function [0,0,0,0,0.75,1,0.25], F^L_{AV} = failure likelihood is Average with membership function [0,0,0.5,1,0.5,0,0] and C^s consequence severity is Marginal with membership function [0,0,0.8,1,0.25,0]. Firstly, using discrete fuzzy mathematic we need to calculate $F^{CP}_{HL} \times F^L_{AV}$ to have the following matrix using the best fit method expressed in form of matrix,

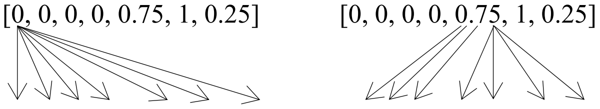
Expert 4: F^L_{AV} and F^{CP}_{HL} and C^S_{MA}

F^{CP}_{HL} = [0, 0, 0, 0, 0.75, 1, 0.25]

F^L_{AV} = [0, 0, 0, 0.75, 1, 0.25, 0]

C^S_{MA} = [0, 0, 0, 0.8, 1, 0.25, 0]

[0, 0, 0, 0, 0.75, 1, 0.25] [0, 0, 0, 0, 0.75, 1, 0.25]



[0, 0, 0, 0.75, 1, 0.25, 0] [0, 0, 0, 0.75, 1, 0.25, 0]

Using the first column for F^{CP} [0] and comparing it with the entire row of F^L gives the first row of matrix M, by taking using the min-max equation 1, [0,0], [0,0],[0,0],[0,0.75],[0,1],[0,0.25][0,0] = [0,0,0,0,0,0,0]. In illustration how matrix is obtained, another example is used. This time, the fourth value in column F^{CP} [0.75] comparing with the entire row F^L result to [0.75,0],[0.75,0],[0.75,0],[0.75,0.75],0.75,1],[0.75,0.25] [0.75,0], highlighted in bold in matrix, *m*. Comparing and completing m, using all column F^{CP} gives,

$$\begin{bmatrix} \{0 & 0 & 0 & 0 & 0 & 0 & 0\} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \{0 & 0 & 0 & 0.75 & 0.75 & 0.25 & 0\} \\ 0 & 0 & 0 & 0.75 & 1 & 0.25 & 0 \\ 0 & 0 & 0 & 1 & 0.25 & 0.25 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$S_1 = C^S_{1\,O}\, F^L_{1\,X}\, F^{CP}_1$$

The next step is to calculate $C^S_{1\,O}\, F^L_{1\,X}\, F^{CP}_1$, where $F^L_{1\,X}\, F^{CP}_1$ is the resultant matrix *m*, and C^S is [0, 0.25, 1, 0.75, 0, 0, 0] a new matrix *n*

$$\overset{m}{\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.75 & 0.75 & 0.25 & 0 \\ 0 & 0 & 0 & 0.75 & 1 & 0.25 & 0 \\ 0 & 0 & 0 & 1 & 0.25 & 0.25 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}} \overset{n}{\begin{bmatrix} 0 \\ 0.25 \\ 1 \\ 0.75 \\ 0 \\ 0 \\ 0 \end{bmatrix}}$$

In this calculation, we take the first row of *m* and compare with entire *n* column, as [0,0][0,0.25],[0,1][0,0.75][0,0][0,0][0,0] where the min value is selected to give, o_{1n} , = [0,0,0,0,0,0,0] then the max value is selected from resultant matrix o_{1n} = 0.

Another example is here in presented for fourth row of m, and compare with entire n column as [0,0][0,0.25][0,1][0.75,0.75][0.75,0][0.25,0][0,0] where the min value is selected to give, o_{4n} = [0,0,0,**0.75**,0,0,0], then the max value is selected from resultant matrix o_{4n} = [0.75]

Therefore the result set of new matrix o_{mn} is obtained to as [0,0,0.75,1,0.25,0]. Therefore,

$F^{CP}_{HL}\, F^L_{AV}$, $S_{13}^1 =$ *[0, 0, 0, 0.75, 1, 0.25, 0]*

Table 12 of safety for B1 example

$S_{i\mu}$	Categories						
	1	2	3	4	5	6	7
P	0	0	0	0	0	0.75	1
A	0	0	0	0.5	1	0.25	0
G	0	0.25	1	0.5	0	0	0
E	1	0.75	0	0	0	0	0

The next step is to calculate D, using equation 3. Using the resultant $F^{CP}_{HL}\, F^{L}_{AV}$, S_1^1 = *[0, 0, 0, 0.75, 1, 0.25, 0]* compared with Table 12 safety expression. Starting with comparing $F^{CP}_{HL}\, F^{L}_{AV}$, S_1^1 with safety expression poor expressed:

[0, 0, 0, 0.75, 1, 0.25, 0] and [0, 0, 0, 0, 0, 0.75, 1]

Then, D can be calculated using equation 4,
$D_{1\,Poor} = \surd\ (0\text{-}0)^2 + (0\text{-}0)^2 + (0\text{-}0)^2 + (0\text{-}0.75)^2 + (0\text{-}1)^2 + (0\text{-}0.25)^2 + (0\text{-}0)^2 = \underline{1.274}$

Again the same for safety expression 'average' is expressed:

[0, 0, 0, 0.75, 1, 0.25, 0] and [0, 0, 0, 0.5, 1, 0.25, 0]
Then, D can be calculated using equation 4,
$D_{1\,Average} = \surd\ (0\text{-}0)^2 + (0\text{-}0)^2 + (0\text{-}0)^2 + (0.5\text{-}0.75)^2 + (1\text{-}1)^2 + (0\text{-}0)^2 + (0\text{-}0)^2 = \underline{0.25}$

For safety expression 'good' is expressed:

[0, 0, 0, 0.75, 1, 0.25, 0] and [0, 0.25, 1, 0.5, 0, 0, 0]
Then, D can be calculated using equation 4,
$D_{1\,Good} = \surd\ (0\text{-}0)^2 + (0\text{-}0.25)^2 + (0\text{-}1)^2 + (0.75\text{-}0.5)^2 + (1\text{-}0)^2 + (0.25\text{-}0)^2 + (0\text{-}0)^2 = \underline{1.479}$

Lastly, the safety expression 'excellent' is expressed:

[0, 0, 0, 0.75, 1, 0.25, 0] and [1, 0.75, 0, 0, 0, 0, 0, 0]
Then, D can be calculated using equation 4,
$D_{1\,Good} = \surd\ (0\text{-}1)^2 + (0\text{-}0.75)^2 + (0\text{-}0)^2 + (0.75\text{-}0)^2 + (1\text{-}0)^2 + (0.25\text{-}0)^2 + (0\text{-}0)^2 = \underline{1.785}$

From the Value of D calculate $D_{smallest} = 0.25$

Using equation 5, the value 'α' can be calculated thus:

$\alpha_1 = D_{smallest} / D_{1\,Poor} = 0.25/1.274 = 0.196$
$\alpha_2 = D_{smallest} / D_{1\,Average} = 0.25/0.25 = 1$
$\alpha_3 = D_{smallest} / D_{1\,Good} = 0.25/1.479 = 0.169$
$\alpha_4 = D_{smallest} / D_{1\,Excellent} = 0.25/1.785 = 0.14$

The sum total $\alpha_{TOTAL} = 0.196+1+0.169+0.14 = 1.505$

Using equation 6, the value 'β' can be calculated thus:

$\beta_1 = \alpha_1 / \alpha_{TOTAL} = 0.196/1.505 = 0.1302$
$\beta_2 = \alpha_2 / \alpha_{TOTAL} = 1/1.505 = 0.66$
$\beta_3 = \alpha_3 / \alpha_{TOTAL} = 0.169/1.505 = 0.112$
$\beta_4 = \alpha_4 / \alpha_{TOTAL} = 0.11.505 = 0.093$

Therefore the safety expression is expressed thus:

S^1_1 = [0.1302 poor, 0.66, average, 0.112 good, 0.093 excellent].

Similarly following the same calculations, the safety expression for remaining experts is expressed thus:

The safety expression for exert 2 on base event 1, S^2_{13} is S^2_1 = [0.35 poor, 0.304, average, 0.177 good, 0.163 excellent].

The safety expression for expert 3 on basic event 1, S^3_1 is S^3_{13} = [0.134 poor, 0.59, average, 0.156 good, 0.105 excellent].

The safety expression for expert 4 on basic event S^4_1 is S^4_1 = [0.278 poor, 0.374, average, 0.168 good, 0.1.75 excellent].

The safety expression for expert 5 on basic event S^5_1 is S^5_{13} = [0.263 poor, 0.263 average, 0.246 good, 0.227 excellent].

7.4 (a) ER Aggregation

The mathematics of using two experts is established in section 5. Where five experts are involved hand calculations using all equations can be troublesome. Hence software such as '*Hugin*' is developed. One important parameter is to note the weight of the five experts in this study. Expert 1, 2, 3, 4, and 5 is assigned a weight of 0.1,0.25,0.5,0.5 reflecting their respective experience in the floating dry dock industry where expert 4 and expert 5 might have the same experience in different region of the world defined as having successfully carried out more than 500 docking and undocking evolution in the past 10 years.

Hence 0.1 stands for 100 docking evolution. Once the weight is identified, the next step is to identify the gate to which each base event is assigned. For example for middle event 1 its base events is associated with an OR gate where all the inputs events of the gate must be given equal weight to that of the output event of the gate.

Conversely for an AND gate the relative weight of all the input events of the gate are assigned through dividing the relative weight of the output event of the gate by the number of the input events (this is important in aggregation process, where fault tree is software is not available, hence the weight of the input event must be evaluated as such).

In this study, the risk analyst is interested in computing the value of Q in equation 16, and input it into the fault tree analysis to run results for risk control options and decision making. Using the '*Hugin*' software, the aggregated output safety (SAO) expression for base event B1 with 5 experts and identified weight is inserted into the software and the results for the safety expression output obtained:

SAO^1 = [0.270 poor, 0.3005, average, 0.185 good, 0.244 excellent].

Using equation 16, to get the 'crisp value' for fault tree analysis for base event B1, 'Q', can be used to expressed SAO^1 as follows;

$$\mathbf{Q} = 0.217 \times 0.270 + 0.478 \times 0.3005^2 + 0.739 \times 0.185^3 + 1 \times 0.244^4 = \underline{\mathbf{0.109}}$$

7.4 (b) FTA Quantification

At this stage, the risk level of each risk item identified in risk assessment was a measured as dataset by expert. The risk level calculated by both hand-calculation in first part of risk assessment and also by using the '*Hugin*' software to aggregated the resultant value of 'Q' required for quantification purposes, Table 13 show the probability of each base event items. The fault tree software (Isograph) is used to run the analysis and the occurrence probability of top failure was 0.109 as presented in Figure 10, where 0.109 means that risk occurs once a year, while 0.64 means hazard occurs twice a year (Njumo, 2013).

A Fault tree analysis software package (Isograph) not only computes the occurrence of top event, hence by passing time wasting hand calculations, it also provides importance of middle events which is an important part for risk analysis decision making.

The fault tree software further presents a results that the importance of the middle events are the same. The next step is to identify risk control options (RCO) and designing a risk control measure program.

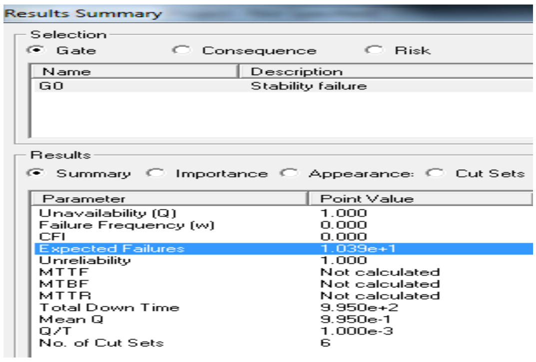


Figure. 10: Expected failure rate

7.5 DESIGN RISK CONTROL OPTIONS

The effectiveness of risk control options in any defined study within the scope of research in shipyard, are based on risk analysis. Questionnaires and literatures are reviewed on existing regulations or operation design to reduce specific risks in area of study. Improvement analysis is carried out by controlling failure events of FT in a quantifiable manner. The recent software analysis has been developed to carry out this analysis and provide results on importance of middle event, hence the corresponding risk control options ranking. The risk control measures in this study has attributes such as: relating to fundamental type of risk reduction (preventive or mitigating), those related to action and costs required and finally those related to confidence that can be poured within active or passive limits of study.

Table 13: Failure Rates (Q_i)

BE	Safety expression	Q	M
B1	[17.15% P, 26.55% A, 32.09% G, 23.40%, E]	0.102	
B2	[16.60% P, 21.38% A, 35.31% G, 26.70%, E]	0.095	M1
B3	[12.89% P, 23.71% A, 48.01% G, 15.31%, E]	0.137	
B4	[16.58% P, 44.45% A, 22.51% G, 16.47%, E]	0.139	
B5	[18.70% P, 53.40% A, 15.54% G, 12.54%, E]	0.179	
B6	[18.64% P, 20.37% A, 33.57% G, 27.42%, E]	0.093	M2
B7	[13.94% P, 56.41% A, 16.81% G, 12.85%, E]	0.186	
B8	[16.60% P, 21.38% A, 35.31% G, 26.70%, E]	0.095	
B9	[16.84%P, 26.95% A, 32.33% G, 23.89%, E]	0.099	
B10	[18.64% P, 20.37% A, 33.57% G, 27.42%, E]	0.093	M3
B11	[16.14% P, 16.80% A, 34.41% G, 32.65%, E]	0.083	
B12	[13.40% P, 44.61% A, 28.04% G, 12.96%, E]	0.141	
B13	[15.83% P, 31.02% A, 31.63% G, 21.52%, E]	0.106	M4
B14	[13.94% P, 56.41% A, 16.81% G, 12.85%, E]	0.186	
B15	[19.44% P, 38.13% A, 23.43% G, 19.00%, E]	0.126	
B16	[13.39% P, 44.60% A, 32.09% G, 23.40%, E]	0.086	M5
B17	[18.70% P, 53.40% A, 15.54% G, 12.54%, E]	0.179	
B18	[12.89% P, 23.71% A, 48.01% G, 15.31%, E]	0.137	
B19	[17.15% P, 26.55% A, 32.09% G, 23.40%, E]	0.102	M6
B20	[15.83% P, 31.02% A, 31.63% G, 21.52%, E]	0.106	

For middle event M1 the risk control measures include (1) improve calculations on draught and trim, (2) improve understanding on stability criteria, (3) careful study of weight increases, (4) improve understanding about recalculating new stability characteristics when any changes occurs. The risk control measure for middle event M2 includes; (1) wing wall redesign, (2) incorporate height of keel in stability checks, (3) careful note on total weight distribution on the blocks (4). Risk control measures for middle event M3 includes; (1) check effects of water plane and, (3) check for negative GM during operation. Risk control measure for middle even M4 includes; (1) improve knowledge of critical phase of intact stability, and (2) check for unexpected shift of centre of gravity. Risk control measure for middle event M5 includes; (1) carrying out proper differential ballasting, (2) carry out proper transitional control of dock, (3) improve wear out checks. Risk control measures for middle event M6 include; (1) check for effects of excessive rudder movement, (2) check for effects of increased wave action generating roll motion, (3) check for strong wings.

This study is evaluated by the risk control measures provided for each middle event, where by six risk control options (RCOs), RCO1, RCO2, RCO3, RCO4, RCO5, and RCO6 represents the risk control measures of middle event M1, M2, M3, M3, M4, M5, and M6. The results from the software rank the RCOs according to importance. The experts linguistic interpretation says that though the system can fail once a year, its middle events or corresponding RCOs are to be treated with the same importance from risk perspective, whereby reducing the occurrence of any of the middle events greatly improves the overall safety of dry dock failure due to stability concerns.

7.6 EVALUATE THE SYSTEM

System evaluation provides the appropriate information on what floating dry dock systems need to do to prevent future happenings of failure. The requirements mentioned in this study through risk control options are tested for accuracy and completeness to ensure that failure models captures the reality of variables performing functions of docking and undocking a vessel under various loading conditions.

This is conducted in two phase to include; expert evaluation and potential user evaluation. In expert evaluation, the measure of the effectiveness of risk control options is revisited. In this approach, experts display knowledge that items to measure the usability of dry dock system reflect some usefulness and eases better understanding of base events B1 to B20. Potential users of this model, presented good judgement of the ease of interaction, extent of capabilities, its efficiency, its speed, its reliability and the significant impart for redesigning the system. The results from both evaluators was positive in assisting and assessing risk associated with floating dry dock, and provided a means to collect, store and analyse potential risk, while monitoring and updating risk mitigation where appropriate for future design.

7.7 DECISION MAKING

Learning to operate a system from risk was made easy by the discrete fuzzy evidential reasoning approach. The interaction with the system made clear and understandable assumptions in the goal to select the best RCO which reduces risk to desired level. The desired level of risk reduction is encouraged in this study by applying all six RCOs with no particular other. Rather this study was made flexible and self-explanatory for any friendly docking and undocking environment.

8. DISCUSSION

This study has presented an engineering project risk analysis using fault tree discrete fuzzy evidential reasoning approach. The procedure was applied in stability failure of a typical floating dry docks, with results demonstrating that the difference of risks between middle events share the same importance. For this, 26 risk items deducted from literature review and expert interviews, provided with 6 middle events, and 20 base events.

The results expected were justified in this study, whereby from a perspective of risk analysis and risk control options, ranking of best control options seems inappropriate, unless cost effectiveness analysis is included. Risk reduction to a desired level must be cost effective. The computations involved in the model of fuzzy risk analysis are tedious if performed manually. It is an easy task and the time for risk analysis can be significantly reduced with more members involve in team. This risk assessment helps the managers to determine the overall risk. The benefits of using the system are as follows:

1) Risks associated with floating dry docks are identified. These risks items serve as a checklist that cover possible risk associated with technical and environmental dimensions. Project managers can be informed and be able to recognize the risks associated with the development.

2) Project managers can predict the overall risk of the project before start the implementation. An overall risk index can be used as early indicators of project problems or potential difficulties. Evaluation can keep track to evaluate the current risk level of the system.

3) The system provides an effective, systematic and more natural way by using the proposed fuzzy risk analysis model. Evaluators can just simply use the risk evaluation checklist and use the linguistic terms to evaluate the risk level.

4) Prioritization is necessary to provide focus for important risks. A list of ranked risk items associated with the floating dry dock model will be produced. Therefore, the most serious risk item will be addressed first.

9. CONCLUSION

With costly fatalities due to stability failure in floating dry dock, the importance of risk management cannot be ignored. It is suggested that the process of planning, organisation, monitoring, and control of all aspects of docking a vessel in floating dry dock consisting of risk identification, risk quantification, risk response development, and risk response control requires a detailed system architecture.

The limitations of this study were the reliance on an expert survey to construct fault tree, the consequent requirement for a great effort for data collection, and tedious hand calculation.

10. ACKNOWLEDGEMENT

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