FAULT TREE ANALYSIS (FTA) - FORMAL SAFETY ASSESSMENT (FSA) IN SHIP REPAIR INDUSTRY A MADE EASY APPROACH

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Summary

Fault tree-Formal Safety Assessment (FT-FSA) is the premier scientific method that is currently being used for the analysis of maritime safety and for formulation of related regulatory policy. To apply FSA in this paper, all five steps are considered and critical information highlighted in each step as reviewed in the literature. A novel 15 steps approach of FT-FSA is introduced in the systematic accident scenario considered in this study as emergent phenomena from variability and interactions in shipyard (considered as a complex system).The results of this paper will be useful for guidelines and regulatory reforms in ship repair industry as demonstrated by identifying 'fall from height in ship repair occupational hazards' for recommendation in decision making.

1 INTRODUCTION

In the maritime industry, questions must be asked. Why should the industry have to wait for an accident to occur in order to modify existing rules or propose new ones? The safety culture of anticipating hazards rather than waiting for accidents to reveal them has been used in industries such as nuclear and the aerospace industry. The international shipping industry has begun to move from a reactive to a proactive approach to safety through what is known as Formal Safety Assessment [1]. FSA is a formal, structured and systematic methodology, aimed at enhancing maritime safety, including the protection of life, property, and marine environment, by using risk and cost-benefit assessments. The use of FSA is consistent with, and should provide support to any decision making body [2]. Based on Wang and Trbojevic [3], it is a new approach to marine safety which involves using the techniques of risk and cost-benefit assessments to assist in the decision making process.

First introduced by the IMO as a rational and systematic process for assessing the risk related to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO's options for reducing risks as reference in Maritime Security Committee (MSC cir. 1023, MEPC circ. 392) [4], it has been seconded to none so far.

Before its adoption by IMO, FSA has been an object of research leading to several academic papers worked by Wang [5], Soares and Teixeira [6], & Rosqvist and Tuominen [7]. The relevance of the methodology of FSA over the span of ten (10) years, has been proven in marine and offshore products such as fishing vessels, ports, marine transportation, offshore support vessels, containerships, LNG ships, ship hull vibration, crushing ships, liner shipping, high speed crafts, oil tankers, trail studies of passenger roll on/roll off (roro) vessels with dangerous goods and bulk carriers [8].

The Royal Institution of Naval Architects (RINA) has also published a collection of some 15 papers on the subject, covering various contexts of the problem [9]. FT on the other hand, is an analysing tool, used in FSA.

This paper is developed from statistics and preparatory work by Njumo [10] and Baris [11], on shipyard fatalities from, USA, UK, Turkey, and Singapore. Reports on a critical review of FSA by Kontovas and Psaraftis [1], guided in highlighting the shortcomings of steps in FSA.

The aim of this paper is to show that FT-FSA methodology of safety-relevant scenarios in occupational accidents in shipyard can be analysed. Our exemplary application is a 'Fall from Height' scenario, which deals with concurrently interacting human operations and technical systems. In particular, the assessment considers the risk of falling from height due to scaffold failure. The systematic risk assessment approach portrayed in this paper intends to be an effective means of providing feedbacks to both contractors and designers in shipyards.

The findings and conclusions are of interest to ship repair owners, maritime researchers, and other safety policy and regulator makers in dry docks. Specifically, the audience for this paper is obviously ship repair managers, where FSA as a subject of non-trivial complexity tool, serves to provide a vehicle to explain how resources can be efficiently managed in the system, through identifying, analysing, and proposing improvements on specific critical systems.

This paper is organised as follows: Section 2 presents the statement of problem. Section 3 reviews the FSA steps, and FT method used for evaluation of risk in ship repairing activities. Section 4 is adoption of 15 steps approach in application of FT-FSA. Section 5 presents an illustrative example, followed by discussions.

2 STATE OF PROBLEM

In dry docks, occupational accidents are frequent. An occupational accident is defined as an unexpected and unintended incidence [11], while occupied in an economic activity, which results in one or more workers getting injured or loss of life. Every 15s, a worker dies as a result of occupational accidents or work related diseases. 160 workers have an occupational accident statistically every 15s. Over 2.3 million deaths per year and more than 336 million accidents occur on work annually [12].

In shipyard, these occupational accidents are classified by several statistical agencies under the construction, or repairing topics. Shipbuilding and repair is a complex business, with huge task performed in parallel. Steel handling and processing production process requires great space, which must be inspected, sorted and stored. On these steels, further activities are required, which include blasting, priming, shaping, forming to designed shape, welding to make assemblies, panel, fabrication, block assembly, pre-outfitting, air conditioning, electrical cable fitting, surface preparation and coating [11].

This has been the challenge in respect to shipbuilding and repair system safety, standing out as being complex and uncertain. The adoption of FT-FSA concept will be used to solve existing gaps. Existing gaps within the framework, is the unavailability of experts to carry out proactive risk based approach to deal with accidents and eliminating its occurrence from its origin. FSA consist of five steps. FT is a formal method used in step 1 and 2, in this study.

Hollnagel [13] categorizes these accident models in the following three types:

- A sequential accident model describes an accident as a result of a sequence of events that occurred in a specific order.
- Epidemiological accident model which describes an accident in an analogy with the spreading of diseases.
- Systemic accident model describes the performance of a system as a whole, rather than on the level of cause-effect mechanisms or epidemiological factors.

From a safety assessment point of view, researchers have rather failed to identify which accident model is used. Depending on model of accidents, different methods and result will be obtained.

FT-FSA over the past decades, has received no attention in dry docking industry, as literature review indicates. The purpose of this paper is to introduce FT-FSA methodology in ship repair industry and propose ways of implementation. All steps of FSA are considered and possible pitfalls or other deficiencies are identified, and proposals are made to alleviate such deficiencies, with a view to achieve a more transparent and objective approach in ship repair industry.

FSA is time consuming, and where experts are required, opinion varies and conflicts arise. Researchers are getting fed up with new existing subjective approaches instead of increasing awareness of companies coming together for data collection. The criticism of using MSC guidelines has been strongly submitted by Greece, yet there has been no response on reforms [1].

The different types of analysis provided by researchers have led to increase confusion as to which method is better to use and in what areas. These and many other disadvantages, have led many researchers to avoid the term 'FSA'. Many love eye catching titles like 'risk analysis under uncertainty', etc., yet using the same FSA methodology. In this regard, this paper, revisits the origin of MSC guidelines in application of FSA, in its simplest form, and brings to light short comings that have plagued its application in recent years from adopting a direct approach in its implementation.

This paper, provides a rather, individualistic research, based on time scheduling and critical thinking, hence by passing so many obstacles presented by time wasting generic opinions from experts. Lastly, many researchers limit its application to ships and offshore structures, impairing creative thinking in other maritime sectors. To overcome these disadvantages, the next section, looks closely into FT-FSA framework and its application in shipyard, and weaknesses of each step highlighted.

3 FSA FRAMEWORK IN SHIPYARD

3.1 PREPARATORY STUDY

This is the definition of problem that will be assessed along with any relevant constraints (goals, systems, and operations).The purpose of problem definition is to carefully define the crisis under analysis in relation to the regulations under review or to be developed.

FSA application starts with studious preparation. It is vital for the whole process, to define limits of study, such as dry dock category, operation, and external influences. FSA, too large a scope presents many difficulties. According to Kontovas and Psaraftis [1], most FSA studies fall into this category, hence coordination and project management may arise.

Two other disadvantages highlighted for using too large FSA scope are;

- FSA studies take a long time to arrive at results and,
- methodology used throughout the process cannot be guaranteed due to inconsistency of input data and its details.

In ship repair industry, it is advisable not to include major risk categories for assessment. To overcome these three disadvantages highlighted, precaution must be taken in dock category, and operation. External influences are ignored, to avoid arriving at wrong results. Lastly, generic approach is preferred, to steer clear of unbiased assessments. It is wrong to select accident scenarios for FT-FSA analysis without preparatory exercise.

3.2 HAZARD IDENTIFICATION (HAZID)

The objective of this step is to identify all potential hazardous scenarios in shipyard that could lead to significant consequences and to prioritise them by risk level.

The first objective requires a creative part (mainly brain storming) to ensure that the process is proactive and not only to hazards that have materialised in the past.

In simple FSA studies, historical data can be used, although its disadvantages are highlighted by Davanney [14], where he states, '*caution is required in identifying casualty database and to correctly identify accident causes*.' His view is shared by Kontovas and Psaraftis [1], who carried out a research on critically analysing the pitfalls and deficiencies in application of FSA in maritime research.

They strongly recommended, probabilistic modelling of failures and development of scenarios as an alternative in IMO FSA guidelines, by using formal methods, such as fault trees, event trees, influence diagrams, human reliability analysis, human element analysing process, and possibly others.

The second objective is to rank hazards and to discard scenarios judged to be of minor significance. Ranking is done using available data and modelling supported by expert judgement. Group of experts in dry docks rank risks associated with accident scenario and a ranked risk is developed starting from the most severe. This is done, using the MSC guidelines risk matrix. Estimation of risk related to a hazard identified in Step 1 begins with estimation of frequency (F) from following fractions:

F = No of Casualties/shipyard years, consequence potential, called Potential Loss of Life (PLL) according to FSA guidelines is: PLL = No of Fatalities/shipyard years. Risk = Probability x consequence. Log (Risk) = (Probability) + Log (Consequence). Combining both indices, a third index, the Risk Index or risk ranking number is achieved:

Risk Index= Frequency Index + Severity Index

Equivalent total is to integrate risk index. It makes use of the fact that both the frequency and severity banks of the risk matrix are approximated logarithmically. Table 1 presents the frequency rate and severity value in shipyard.

Table 1: Shipyard Frequency (F) and severity rate (R)

Frequency rate Likely to happen in shipyard	General Interpretation
F4: 1-12 months	Frequent
F2: 2-3 years	Likely to occur
F2: 5-10 years	Remote
F1: Over 10 years	Unlike to occur

Severity Value	**General interpretation in shipyard**
S1	Minor injury
S2	Major
S3	Fatality

Table 2 shows shipyard risk matrix. This risk matrix is *3x3* as opposed to *3x7* matrix proposed by MSC, due to nature of ship repair industry.

A criticism of this method (risk matrix) as a standalone, gives no distinction among hazards that have more than 10 fatalities. Again, in this risk matrix, constructed for all combinations of the frequency and severity indices equations, the probability is equated to frequency, in comparing scenarios in terms of risk, some scenarios stand chances to be ranked lower or higher than required.

Table 2: Shipyard Risk Matrix

S/F	**F1**	**F2**	**F3**	**F4**
S1	1	2	3	4
S2	2	3	4	5
S3	3	4	5	6

Though, risk matrices are not used for decision making however, they constitute a simple yet most important tool that is provided to group of experts in the hazard identification step to rank hazards. These matrices are simple to use, but the above disadvantage, are not ignored in this paper.

In cases where group of experts are asked to rank objects according to one attribute using natural numbers, multi grouping is required. Multinational group of experts is not rare in FSA studies. A number of 10 experts are reasonable for such groups demonstrated in concordance coefficient W in equation 1:

$$W = \frac{12 \sum_{i=1}^{I=i} \left[\sum_{j=1}^{j=J} xij - \frac{1}{2}J(I+1)\right]^{\wedge}2}{J2\ (I3\text{-}I)} \qquad (1)$$

The coefficient W varies from 0 to 1. W= 0 indicates that there is no agreement between the experts. On the other hand, W= 1 means that all experts rank scenarios equally by the given attribute. This equation, can be found in MSC guidelines for detailed study, but has hardly been used in any of its application in maritime research.

3.3 RISK ANALYSIS

The purpose of the risk analysis in Step 2 is a detailed investigation of the causes and consequences of the more important scenarios identified in Step 1. This point is stressed here, because, unlike in many studies, researchers have failed to distinguish step 1 and 2 in this approach. The term '*identify*', means what it says, but in FSA, to identify means, to identify and carry out further work, such as ranking. Ranking leads to risk analysis.

Therefore it must be stressed that, risk analysis is a 'detailed investigation'. The question remains how detailed is it different from step 1, and how much time will a detailed investigation take to be carried out? Again, one may argue that, detailed investigation may vary in research, on this ground, the term a minor and major hazard may differ.

This confusion is studied in Nwaoha *et al.* [8], FSA in LNG. They called risk analysis, 'hazard identification processes'. They stated*, 'in this step, risks associated with the identified hazards of the LNG carrier in step 1, are evaluated to determine if they are significant.*' In this step, according to the passage, step 2 is rather a detailed evaluation of the highest ranked hazards (i.e. step 1 must provide significance of each hazards and not step 2).

Much is more said than done. A simple FSA application can as well be very demanding and time consuming. It is for this reason that, section 3.1 and 3.2 is highlighted for observation to avoid this shortcoming and to illustrate the application of FSA in ship repair industry.

A detailed quantification analysis is required in this step, using casualty historical data and frequencies. The potential pitfall of the quantification of risk as currently applied however may be improved through superior quantification scheme and qualitative scheme (which does not use numbers but ranks risk only in qualitative way), is deemed more reliable.

Kontovos and Psarafis [1], claim that a qualitative approach may be better than a problematic quantitative one. This is not true because as engineers, we must quantify (use numbers). These values provide grounds for risk control options (RCOs) and cost benefits analysis. In cases where the research does not proceed to step 3, 4 & 5, their claims may be valid. The results from risk analysis, is the basis for RCOs analysis.

3.4 FAULT TREE ANALYSIS

Fault tree analysis (FTA), on the other hand, is a very popular and diffused technique for modelling and evaluation of large, safety and critical systems [16]. Fault tree is used in risk engineering to analyse the frequency of system failure either qualitatively by logical and structural hierarchy presentation of failure events or quantitatively by the estimation of occurrence rate of the top event.

It is a deductive analysis, starting with potential or actual failures and deducing their causes. Root causes of failures frequently have to be inferred from multiple indirect observations. Fault trees are intended for reliability and fault analysis rather than diagnostic observation [15].

FTA has wide applications in system safety engineering such as security design, risk assessment, and the management of safety critical projects [16].

FTA is based on identification of a particular undesired event to be analysed (e.g. system failure), called a Top event (TE). The construction of Fault tree (FT) proceeds in a top down fashion, from events to their causes, until failures of basic components are reached [17]. It is developed and based on following assumptions:

- Events are binary events (working/not working)
- Events are statistically independent and;
- Relationships between events and causes are represented by means of logical 'AND' and 'OR' gates.

FT is introduced, in this step, due to its graphical representation, and the use of computerise reliability workbench such as ISOGRAPH.

Detailed on the history and application of FTA is as referenced [16] for further studies. FTA is a preliminary safety analysis tool, with the qualitative approach of identifying the root causes of the development of RCOs. FTA is an effective methodology in the safety analysis of system. Among the 15 Publications in RINA, there have been a total of 10 FTA in safety research.

3.5 RISK CONTROL OPTIONS (RCOs)

The purpose of this step is proposing effective and practical RCOs compromising of the following three steps [18];

- focusing on risk areas needing control, identifying potential risk control measure,
- evaluating the effectiveness of risk control measures (RCM) in reducing risk by evaluating step 2,
- grouping the RCMs into practical regulatory options.

Risk control measures should be aimed at; reducing the frequency of failures, mitigating the effort of failure, alleviating of circumstance where failures may occur, and mitigation of the consequences of accidents in shipyards. The purpose of this step is to avoid considering any implementation costs.

3.6 COST BENEFIT ANALYSIS

This step is aimed at identifying and quantifying the cost to be paid and benefit to be expected when each RCO is implemented.

In general, the cost component consists of the one-time (initial) and running cost of an RCO, cumulating over the lifetime of the system. The benefit part is much more intricate. It can be a reduction in fatalities or a benefit to the environment, or an economic benefit for preventing a loss of shipyard [1]: It is calculated using equation 2:

$$CAF = CURR = \sum_{t=0}^{n} \frac{(b-c)\left\{\frac{[1+i]}{[1+r]}\right\}^{\wedge}t}{1} \quad (2)$$

Where *b* and *c*, are benefit and cost respectively, *r* is the discount rate of 4%, *t* is the measure of time horizon from *0* to *n* years, and *i*, is the inflation or wage increase. Each RCO is evaluated in terms of implementation cost and then by deriving its associated cost per unit reduction in risk (CURR). The cost benefit assessment as highlighted in MSC guidelines consists of;

- considering the risks assessed in step 2,
- arrange the RCOs, defined in step 3 in a way to facilitate understanding of costs and benefits resulting from the adoption of RCO,
- estimate and compare the cost effectiveness of each option, in terms of the cost per unit reduction by dividing the net cost by the risk reduction achieved as a result of implementing options,
- rank the RCOs from cost-benefit perspective in order to facilitate the decision making recommendation in step 5.

However an extensively used index in FSA is the so called Cost of Averting a Fatality (CAF) and can be expressed in two forms:

Gross Cost of Averting a Fatality (GCAF) $= \frac{\Delta C}{\Delta R}$
Net Cost of Averting a Fatality (NCAF) $= \frac{\Delta C - \Delta B}{\Delta R}$

Where,
ΔC is the cost per shipyard of the RCO under consideration, ΔB is the economic benefit per ship resulting from the implementation of the RCO, ΔR, the risk reduction per shipyard, in terms of the number of fatalities averted, implied by RCO.

3.7 DECISION MAKING

Recommendation for decision making is the final step of FT-FSA. This aims at providing recommendations to the relevant decision makers for safety improvements, taking into consideration findings during previous steps. RCOs recommended should reduce risk to the 'desired level' and be 'cost effective'.

Recommendations presented must be relevant to decision makers in an auditable and traceable manner. These recommendations are based upon the comparison and ranking of all hazards and their underlying causes.

The foregoing analysis provides a sound basis upon which decisions about safety improvements in shipyards can be made. The systematic nature of this method gives confidence in results to facilitate decision making in any model under study in shipyard.

4 FIFTEEN (15) FT-FSA STEP APPROACH

4.1 DEFINE WORK

The work definition in this paper is risk analysis in shipyard repair activities. This does not include the operation of bringing a ship out of water for repair or launching a newly built ship. The emphasis on these results and conclusions are on ship repairing or construction activities already on site.

4.2 CHOOSE GOALS & SET CONSTRAINTS

The goal is to identify shipyard fatalities. Goals are to expand research casualty data base, and accumulate results. Identify related work, and extract required information. Casualty data base is from Turkey, UK, USA, and Singapore.

An example of the constraint in this study is, work in shipyard is carried out at normal weather condition (e.g. good weather). Due to large volume of data analysed from the period of 1990-2011, comprising of more than 100 shipyards in data, no generic shipyard is required to be developed.

4.3 SELECT RISK ANALYSIS METHOD

Expert grouping for brain storming is by passed in this study, due to available data and detailed reporting on accident for selected illustrative example. A generic case is developed on generic ranked hazards for detailed analysis. FTA is selected for use in Hazard identification and detailed risk analysis.

4.4 DRAW FTA FOR HAZARD IDENTIFCATION

FTA is constructed for 15 identified hazards from data collected. This step, is quite tedious, but fault tree graphical representation, makes sure nothing is missing during analysis.

4.5 RISK MATRIX ON HAZARD IDENTIFIED

3x3 risk matrix developed in section 3.2, is preferred in hazard identification study in shipyard as opposed to *7x4* matrices in the MSC guidelines.

4.6 CALCULATE EQUIVALENT TOTAL

This calculation is required in hazard identification step, so as to focus on those hazards above number 3, as illustrated in risk matrix in section 3.2.

4.7 HAZARD RANKING

The top ranked hazards are identified and noted for further analysis. In ship repair industry, special attention however must be paid to the nature of constraints, and scopes of study defined in section 4.1.

4.8 FTA QUANTIFICATION PROCESS

From hazard ranking carried out, a detailed quantified FTA is carried out on identified hazards with greatest risk. In other words, one accident might have 3 different scenarios. The greatest risk among these scenarios should be selected for detailed analysis. In some cases, where the equivalent total of each scenario is the same, then the quantification process highlights which is of greater risk.

Results from the five (5) top hazards are ranked, and any can be selected for further analysis, depending on goals set in section 4.1-4.3 and time consideration.

4.9 FAILURE RATE OF TOP EVENT

Engineering knowledge is acceptable here. In this study, basic events are provided with probabilities of failure, to compute the occurrence failure rate of the system under study.

A Fault tree analysis software package (Isograph) computes the occurrence of top event, hence by passing time wasting hand calculations. This software provides the basis through which the popular '*minimum cuts sets analysis*' can be by passed, due to RCM and CURR analysis for decision making.

4.10 IDENTIFY RCO

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.

4.11 GROUPING RCO INTO RCM

These grouping allows for risk control measures (RCM) to be applied appropriately.

4.12 RCM ANALYSIS

Improvement analysis is carried out by controlling failure events of FT in a quantifiable manner, and in every analysis, the top improvement of top event is noted.

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 within the study in ship repair.

4.13 CURR ANALYSIS

Cost benefit analysis is carried out by using equation 2 and results from section 4.12. CURR analysis requires the time horizon for this study to be on zero wage and inflation rate. A discount rate is recommended for analysis to be in the range of 3-6%.

4.14 COMPARE EFFECTIVE CURR AND RCM

This step is to compare improvement in RCOs and values obtained from CURRs. This study shows that the benefit of a measure outweighs the approximated costs. A base case approach is usually encouraged to use in ship repair industry, where available facts are published and obtainable.

4.15 DECISION MAKING

Select best RCO which reduces risk to desired level. The desired level judgement is by results obtained from detailed FTA.

Ranking of RCOs is required for effective management of resources were appropriate. Risk reduction to a desired level must be cost effective.

Guidelines are required to be adopted from both individual and societal type of risk perspective should be considered for decision making in ship repair industry.

5 ILLUSTRATIVE EXAMPLE

5.1 DEFINE WORK

The top 5 fatal accidents in shipyard are ranked thus: falling from height, exposure to electric shock, fire and/or explosion, being struck by or struck against objects, and caught in between (squeeze) [10, 11].

Following steps 4.1-4.7, fall from height in shipyard ranked among top five hazards in ship repairing industry, is selected for detailed studies in section 5.2.

5.2 CALCULATING EQUIVILENT TOTAL

After an intensive search for fatal accidents between 1990-2010, the most frequent types of tasks performed when falling from height accidents were, falling from the deck, from the scaffolding, during welding, blasting, and painting, and falling while walking. The equivalent total for these 5 scenarios identified were calculated and fall from height due to scaffold failure was greater, and selected for further studies.

Equivalent total fall from height due to scaffold failure;

3 + log (300+30+1) = 5.6 [10]

5.3 FAULT TREE ANALYSIS

The top event fall from height due to scaffolding failure is analysed. The frequency of occurrence as obtained from Program-Based Engagement for Scaffolding, workplace safety and health advisory committee (WSHAC) is 15 per shipyard year [19].

The total risk summarised in this study include, structural damage, potential loss of life, and financial cost incurred if this hazards occurs. The probable risk caused by fall from height due to scaffold failure is estimated to be about 159,350 in fines a year from statistic of OSHA reports [20]:

"Improperly erected scaffolding and failure to train workers on the hazards of working with scaffolding which resulted in the deaths of five workers and injuries to ten more resulted in citations against three New York contractors - Nesa, Inc, Tri-State Scaffolding & Equipment Supplies, Inc., and New Millennium Restoration & Contracting Corp., - and $159,350 in penalties, according to the U.S Times report."

The failure rate for basic events assigned in this study for engineering analysis is by expert knowledge. Table 3, shows seventeen (17) basic events and each value as indicated. The result for analysis is graphically represented and obtained in Figure 1, which shows a failure rate of top event P (T) = 0.281, at time t = 100 hours and P (T) = *G1*+ *G2*+ *G3*+ *G4*, where G1, G2, G3, G4, represent failure gates for improper use of fall arrestor, lack of PP, improver positioning, and unstable scaffold structure respectively.

Table 3: Basic event with failure rates

Event	Failure Rate	Event	Failure Rate	Event	Failure Rate	Event	Failure Rate
1	0.7	**5**	0.003	**9**	0.07	**13**	0.08
2	0.6	**6**	0.004	**10**	0.001	**14**	0.1
3	0.02	**7**	0.05	**11**	0.02	**15**	0.005
4	0.8	**8**	0.006	**12**	0.002	**16**	0.7
						17	0.6

Total cost at failure rate (0.281) = $160,000

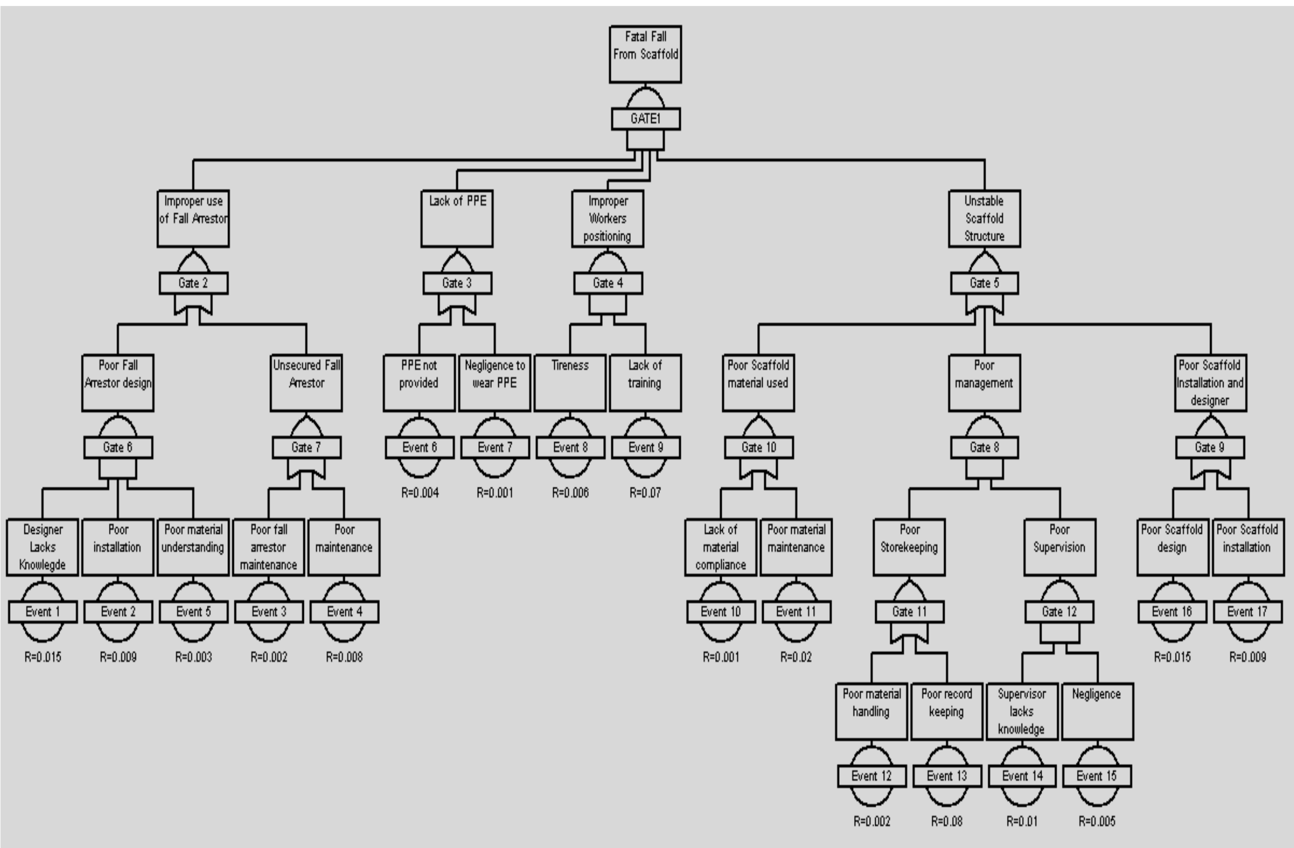

Fig. 1: Failure rate of top event fall from height due to scaffold failure

Table 4: Basic events under RCO grouping

Basic Event and areas of risk control measures required	***Failure Rate***	***Risk Control measures grouping***	***Potential Risk***		
1.lack of scaffold designer knowledge	0.7		Loss of life	Structure damage	Loss of production cost/fines
2. lack of fall arrestor designer knowledge	0.7		-	-	-
3.Poor scaffold installation	0.7	RCO2	-	-	-
4. Poor arrestor installation	0.6		-	-	
5. PPE not provided	0.04	RCO1	-	-	-
6. Negligence put on PPE	0.05		-	-	
7. Poor scaffold material understanding	0.003	RCO3	-	-	
8. Poor Fall arrestor material handling	0.02		-	-	
9.lack of material compliance	0.001		-		-
10. Poor material inspection	0.2	RCO3		-	-
11. Poor material maintenance	0.5		-	-	-
12. Poor material house keeping	0.5		-		
13. Poor material record keeping	0.4	RCO3		-	
14. Tiredness	0.006				
15. Lack of Training	0.07	RCO2		--	
16. Negligence	0.03				

Table 5: Percentage reduction in RCOs

15% RCO 1	**Failure Rate**	**85% RCO 2**	**Failure Rate**	**40% RCO 3**	**Failure Rate**	**35% RCO 4**	**Failure Rate**
6	6.0e-4	**1**	1.2e-3	**12**	8.0e-4	**8**	2.1e-3
7	5.2e-3	**16**	1.2e-3	**5**	1.2e-3	**9**	2.4e-2
	0.002	**17**	7.5e-3	**10**	4.0e-4	**15**	1.7e-3
	0.008	**2**	7.5e-3	**11**	8.0e-4	**14**	3.5e-3
				3	8.0e-4		
				4	3.2e-3		
				1	3.2e-3		

Table 6: Re-calculated occurrence probability of TE

Risk Control Options	**Initial Occurrence probability of top event (I)**	**Re- Calculated occurrence probability of top event (R)**	**Differences**	**% Reduction (I-R/I) *100**
RCO1	0.283	0.116	0.167	59%
RCO2	0.283	0.211	0.072	25%
RCO3	0.283	0.097	0.186	65%
RCO4	0.283	0.076	0.207	73%

Table 7: CURR of RCO1-RCO4

RCO	1		2		3		4	
	C1	**B 59% C1**	**C2**	**B 25% C2**	**C3**	**B 65% C3**	**C4**	**B 72%C4**
O	5000	2,950	9500	2,375	25,000	16,250	15,000	10,800
T	5000	2,950	9500	2,375	25,000	16,250	15,000	10,800
R		1		2		3		4

O –Operator cost, **T** –Total cost in \$, **R**-Reduction

5.4 RISK CONTROL MEASURE ANALYSIS

RCO1 includes provision of PPE at all times, RCO2 is improving scaffold design, RCO3 is improving housekeeping/maintenance/inspection and RCO4 is improve training for workers at height. Table 4 represents risk control options and ranking implemented for analysis. These are ranked into risk control measures. The potential risk if these options are not implemented includes loss of life, loss of production cost/fines, and structural damage (requiring re-designing).

Analysis is carried out by reducing some risk control options in fault tree, while others remain constant. Reducing the failure rate of some basic events would be vital to illustrate the different stakeholders, owners and designers about the need for improving safety in shipyard.

Therefore, reducing failure rate of events 6 & 7 indicates proper implementation of RCO1 as in Table 5, while other basic events remain unchanged. The value of failure rate of top event P (T) is reduced from 0.283 to 0.116 (59% reduction) noted in Table 6. In Table 5, when RCO2 and RCO 3 are implemented, the value of the reduction in failure rate of top event is noted. Lastly, results obtained when RCO4 is implemented (i.e. reduction of failure rates of basic events 8, 9, 15, and 14) by 35%. There is a general reduction of the top event by 73%. The occurrence probability of top event is reduced from 0.2831 to 0.076

5.5 COST BENEFIT ASSESSMENT

Cost benefit assessment is carried out to obtain the best risk control measure for decision making analysis. For better understanding, an example is used.

The cost proposed by OSHA for providing training to workers at height is $15,000 a year (RCO4). The benefit enjoyed from implementing this risk control option would reduce the occurrence probability, "for fall from height due to scaffold failure", by 73% hence, reaping a benefit of 10, 800 (72% of 15,000) as indicated in Table 6. It is important to understand the benefits of risk control measures from the financial aspects.

Another example is presented with cost estimated for improving scaffold material, maintenance, housekeeping and record keeping (RCO3) to be $ 25,000 a year. The occurrence probability of top event is reduced to 65% when *RCO3* is implemented. In this light, the benefits obtained upon the implementation of *RCO3* is $16,250 (65% of 25,000) presented in Table 7, from which CURR is calculated.

Assuming that the time horizon for the safety assessment is for 10 years at a discount rate of 3%, and using equation 2, the CURR calculation for each RCO is given as follows:

$$CURR1 = \sum_{t=0}^{10} \frac{(5000 - 2950)(1+0.03)^{-t}}{1} = \underline{\$\ 17,486}$$

$$CURR2 = \sum_{t=0}^{10} \frac{(9500 - 2375)(1+0.03)^{-t}}{2} = \underline{\$\ 30,285}$$

$$CURR3 = \sum_{t=0}^{10} \frac{(25000 - 16250)(1+0.03)^{-t}}{3} = \underline{\$\ 24,882}$$

$$CURR4 = \sum_{t=0}^{10} \frac{(15000 - 10800)(1+0.03)^{-t}}{4} = \underline{\$\ 8,956}$$

5.6 RECCOMENDATION FOR DECISION MAKING

It is noted clearly from the calculations that if CURR is used as the only measure of effectiveness in decision-making process, the most effective RCO would be *RCO4*. *RCO1* would be the next and *RCO2* the least effective according to the cost benefit analysis. However, initial benefits for implementing *RCO3* are higher than that of *RCO4* in Table 6.

This is a strong indication of the short coming which could arise if CURR is used as the unique tool for decision making. Therefore, care is vital by decision makers on what '*grounds of confident*' is taken into consideration as either a *'long term*' or '*short term'*, will give different results since CURR is '*time dependent*'.
This recommendation can help: increase safety awareness among workers in shipyard and reduce accidents considerably. If housekeeping, adequate training, and accidents investigated retrospectively, then causes of the accidents and the number of nonfatal accidents investigation will help clarify any inconsistency.

Model calculations naturally do not provide a decision. Decisions can only be taken if a corresponding rule is available, which is to be applied to model results in shipyard. This corresponding rule is adopted in FT-FSA, through the deterministic made easy approach carried out throughout this work.

6 DISCUSSION

The increase in failure frequency in shipyard which is deemed not acceptable is a criterion to be investigated by outside analyst. The above results demonstrated that it must be borne in mind that the type and scope of analysis as well as the number of impact of conservative assumptions must have a bearing on results for decision.
This paper describes an approach of FT-FSA in shipyard safety analysis in order to test the efficiency of case study selected to validate the direct approach introduced. This quantitative approach provides advantages over qualitative by providing values for effective analysis.

Secondly, the use of software in FTA makes analysis easier. This example shows the efficacy of any decision making process defined in shipyard risk analysis process. This methodological framework for dealing with hazards from potential harmful effects to workers provides a rational basis for deciding whether upgrading is required or not and which components should be upgraded in every given shipyard activity rank among top hazards.

Based on data collected throughout the application of this methodology, it is thought that detail descriptions of accidents in future, happening in shipyard should be properly recorded and documented. Strict decisions are required by engineering analyst in FT, RCO and CURR analysis.

In future, there are many interesting directions to extend the research of FT-FSA approaches. For example, the approach in this paper can combine FT-Bayesian and other safety analysis methodologies.

7 CONCLUSION

With costly fatalities due to fall from height in shipyard, strengthening safety investigation can avoid natural, situational and historical causes of these accidents. To guarantee safety against fall from height, the reliability targets need practical translation and constant attention, through effective solutions provided in this paper. The case study shows that FT-FSA can be used for predicting the occurrence probability of basic events, which is often used to identify the criticality of the basic events. Controlling the occurrence of these crucial events would considerably reduce the possibility of accidents.

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