HUMAN ERROR RISK ASSESSMENT MODEL FOR SHIPPING MAINTENANCE PROCEDURES IN HARSH ENVIRONMENTS

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Abstract – *Human factors play a significant role in increasing the operational safety of maritime transport and offshore facilities. A significant number of human errors occur during the maintenance phase. However, the qualification of human error interpretation before undertaking any quantification in the maintenance procedure should be given more attention. It is necessary to find a reasonable qualitative non-linear based method with good interpretation of WHY and HOW accidents occur. This provides good insight, sources of risk and the possibilities for minimizing the potential risk. As maritime operations move into Arctic and Antarctic environments, this will become even more crucial. Decision makers must therefore be able to recognize how cold weather affects human performance and work out how availability, survivability or maintenance of a system goes wrong. This will help assessors to review the details of the process and ask relevant questions rather than blindly finding answers. This paper presents a new reciprocal interaction of qualitative risk-based methodology for human error estimation by applying "Functional Resonance Analysis Method" (FRAM). This methodology has the potential to be considered the first step of any future quantitative assessment for human error estimations. The present study is an imperative milestone for coupling between nonlinear qualitative and quantitative based methods in risk assessment to systematically identify human errors. The developed methodology has been applied to a case study for the maintenance of a component in a ship sailing in a harsh environment.*

Keywords: Risk assessment, Human error, FRAM, Maintenance, Shipping, Harsh

1. INTRODUCTION

The study of human factors is an important area of maritime engineering that includes the systematic application of information related to human characteristics and behavior to improve the performance of human-machine systems (Kirwan 1998, Noroozi et. Al., 2010). It is essential to understand human faults that can lead to accidents. Human factors will help risk assessors effectively look for the cause and effects leading to an accident in a scenario and consequently answer wisely the main questions in regard to this issue: (i) Why does an accident occur (Noroozi. A et al. 2014, Abbassi et al. 2015), and (ii) How does it occur (Islam et al. 2017). Additionally, considering a qualitative interpretation of accident in Arctic conditions is prior to any quantitative risk and reliability analysis (Herrera. I et.al., 2010, Noroozi. A et al. 2013). Unique characteristics of Arctic regions and their effect on human performance during maintenance procedures demand a methodology accounting for the effect of cold and harsh environments in the final estimation of HEPs (Dhillon 2013, Islam et al. 2016). Some effects of cold temperature and harsh environments on human performance are listed in Table 1. One of the developed qualitative methods that can consider the above aspects comprehensively is the Functional Resonance Accident Model with the associated Functional Resonance Analysis Method (FRAM), (Hollnagel et al. 2014). FRAM is based on Resilience Engineering method which defines the ability to meet risk (Hollnagel 2012). FRAM approach can identify new nonlinear connections and dependencies without any limitation for observing the various aspects of accident scenarios. In this study, a novel methodology is developed based on FRAM to evaluate the resilience of the operation in case an abnormality occurred in the operation. This means that the methodology does not look at a specific accident scenario, but at normal operations, where a variation in a function can resonate through other functions. It is not surprising then that the resonance can create larger variations that lead to an accident. Therefore, the aim of this study is to visualize the influences which occur between functions and develop a full non-linear qualification representation of human error estimation in order to better understand the system as a whole and optimize HRA process for later quantification purpose. The particular area of application is shipping and offshore operations.

2. BACKGROUND: FUNCTIONAL RESONANCE ANALYSIS METHOD

FRAM is a functional method meaning that it focuses on normal variability in the system and considers variations in the execution of daily operations (Hollnagel. et.al, 2013, Halseth 2012). It is a risk model reviewing non-linear interactions of a social-technical system built on reviewing normal operations applying four main principles, when things are working as they should be. The failures should represent the flip side of the situation and to succeed, the system should have the ability to meet these risks. The system should have the ability to recognize different situations and adjust itself with conditions to overcome possible risks (Herrera and Woltjer 2010). Each activity or task will be changed by a possible variation where the most important of them is human fault. Combination of these variations for different tasks will result in disproportionately greater complications due to its nonlinear effects. These variations can reinforce each other and spread through the network and cause unidentifiable resonance. FRAM itself consist of four steps to analysis a scenario. In the first step, the functions and their characteristics to interpret the specific stages of a scenario should be identified. Function has six aspects in terms of their Input (use to produce Output), Output (Result of what the function does), Pre-condition (situation that must be true and verified), Control (Supervise or regulates a function), Resources (what the function needs to proceed) and Time (which affects the availability of function for a conditional or certain time stages). Function can be illustrated by a Hexagon (See Fig. 1). Functions can be classified as two types being Foreground activities which represent the main focus of the analysis and Background activities which support performance of the set of foreground functions. FRAM presents PSF as well as barrier functions, as a Background function.

Table 1 General Cold Environmental Factors affecting Human Performance (HP)

Stressors	Details
Cold Temperature	Breathing difficulty, muscular stiffness, frostbite, lowered metabolism, hypothermia, bulky clothing
Ice ad-freeze	Stiffness of suits impairing movement, incapacities mechanism, slippery surfaces, adds weight/mass
Combined weather effects	Wind, snow, waves-impair HP
Marine Ice	Precludes rapid descent to sea level, unstable for locomotion
Low visibility	Ice, fog, lack of solar illumination, frost on windows, visor, glasses
Stress	Fear of unknown disorientation

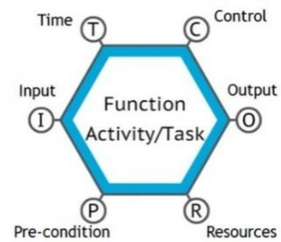

Fig. 1 Function model in FRAM

In the second step, the variations that can emphasize the performance of the functions should be identified. The description of variability is based on the information registered in the incident report combined with a set of questions based on the CPCs (Common Performance Conditions). The CPCs address the combined huMan, Technological and Organizational (MTO) aspects of each function (Hollnagel, 2012). The CPCs are used as the main determinant of the variability of the functions. The combined effect of the CPC is non-linear. Using expert judgment and asking related question about variations that can change the functions, the variability in connection with CPC should be found. Hollnagel, (2005) illustrates how the CPCs can be classified according to the MTO principle. In the third step, with regard to functions and potential functional variability which are identified in steps 1 and 2, the network can be constructed. Simultaneous occurrences of spreading variability may have the effect of resonance which becomes a signal that spreads throughout the system and can be introduced to find any possible accident scenarios. In the fourth step, the variations that a signal can identify in a function should be interpreted. One can then elicit the situation for preventing the accident or see the cause and effect for the occurring accident. Due to lack of preventing options for human activities, a resonance can be dispersed to the entire network.

2.1. A Qualified Risk Assessment Based on FRAM

In this study a qualified methodology is developed to improve the interpretation of non-linear interactions of human activities in marine operations. This will assist in surveying potential accident scenario as well as determining possible safety barriers to minimize human error. Another insight of this new methodology is that it can cover various accident scenarios for a specific operation (e.g. pump maintenance in this study) in a unique task analysis. By means of FRAM and input various signals in the network, one can try to find high risk accident scenario in terms of non-linear interaction of interpretation of socio-technical system.

Application of this methodology and considering resonance and monitoring risk in a system which provides high values of human errors may help to reduce risks which occur due to the human performance in a maintenance task. This ultimately increases the overall safety and reliability of the process facilities. To clarify different steps of the methodology, a flowchart is illustrated in Fig. 2. As is shown, firstly a task analysis interpretation for the process should be defined in detail. FRAM is embedded to provide a strong visualizing tool for developing an accident scenario. A comprehensive study will be applied in this section to identify all possible variations that affect diverse aspects (six parameters related to each function) of the operation. Hereafter, identifying functions and potential variations helps assessors develop a network in regard to introducing reasonable resonance which leads to a high risk accident scenario. One can study barriers in this step or just leave that for later studies in risk management. A risk assessor can track the signal within the network and monitor all possible risk in connection with each potential variation (Step 2) and non-linear interactions of aspects for each function (Step 1). The important outcome at this stage (monitoring risk) is to observe any possible abnormalities during the operation. Therefore, assessors try to impose some barriers to minimize the risk. This will lead to categorizing and ranking imperative performance influence factors which is necessary for further quantitative study.

3. APPLICATION OF METHODOLOGY

3. 1. Scenario Development

A case-study from an offshore process facility including pump maintenance procedures is considered to demonstrate the application of the developed risk-based methodology. The main focus of this study is on qualitative assessment of pre-maintenance of a pump used in a supply vessel for offshore operations. A FRAM network was developed to survey human performance malfunction that may cause accidents during maintenance. To develop the scenario, it is necessary to define background and foreground functions related to all sub-activities and take a global look at task analysis to define the process (Noroozi. A, et.al, 2013). To do this, the normal condition should be considered to develop the network, but not the abnormal one. This will help us to be focused in all aspects of the operation to produce different accident scenarios in future.

3.2. Human Error Assessment

The situation considered for analysis in this study is an event where a pump is removed and reconnected for maintenance from a separation system. During pre-maintenance, there is a critical task related to 'draining and purging lines' (Function No. 4 in Fig. 3) and consequently it is a Foreground function. It is necessary that all isolation valves be closed to remove probable obstacles in the way of bleeds or valves, nevertheless we cannot perform mechanical isolation. These controls should be done in advance (i.e. in foreground 'isolating the component', Function No. 3 in Fig. 3), so this part links to previous Foreground function. However, one should also satisfy all other pre-conditions for draining purpose. For instance, it is better to open all valves and start the pump to test the lines for pressure or test for release check in case there is any evidence of leakage. If the pre-condition is not satisfied, then a worse situation is expected. Inherently these procedures can be continued without verifying the pre-conditions. There will be a possibility for ignition due to sparking that can occur as the work environment faces up to flammable leakage. That is why the detector should find error (another pre-condition to damp the error for imprecise tests and controls for previous background functions 'detectors' and 'tests'). One certain time condition is still remaining, and that is depressurizing the line. It should be done from previous foreground (function No. 3 in Fig. 3). These conditions help to purge the lines and consequently let us get rid of any possible splashes, spray or leaking fluid in site. By satisfying all these aspects, there is an output for the 'complete disassembly' (function No. 5 in Fig. 3), to break containment and be ready for motor tests. The main reason for the variability of this function is the lack of training and experience as well as work condition which can produce enormous errors. As an example, Table. 2 shows the aspects of the function 'Drain/Purge Line' as well as variability that effects functions. Similar tables were developed for other functions in this study (Steps 1 and 2 in Fig. 2). The connections between the functions are modeled using the hexagonal representation of the functions and drawing a line between the aspects to illustrate the link between the aspects of each function to each other. In this study, FRAM Model Visualizer (FVM) is used to construct the networks.

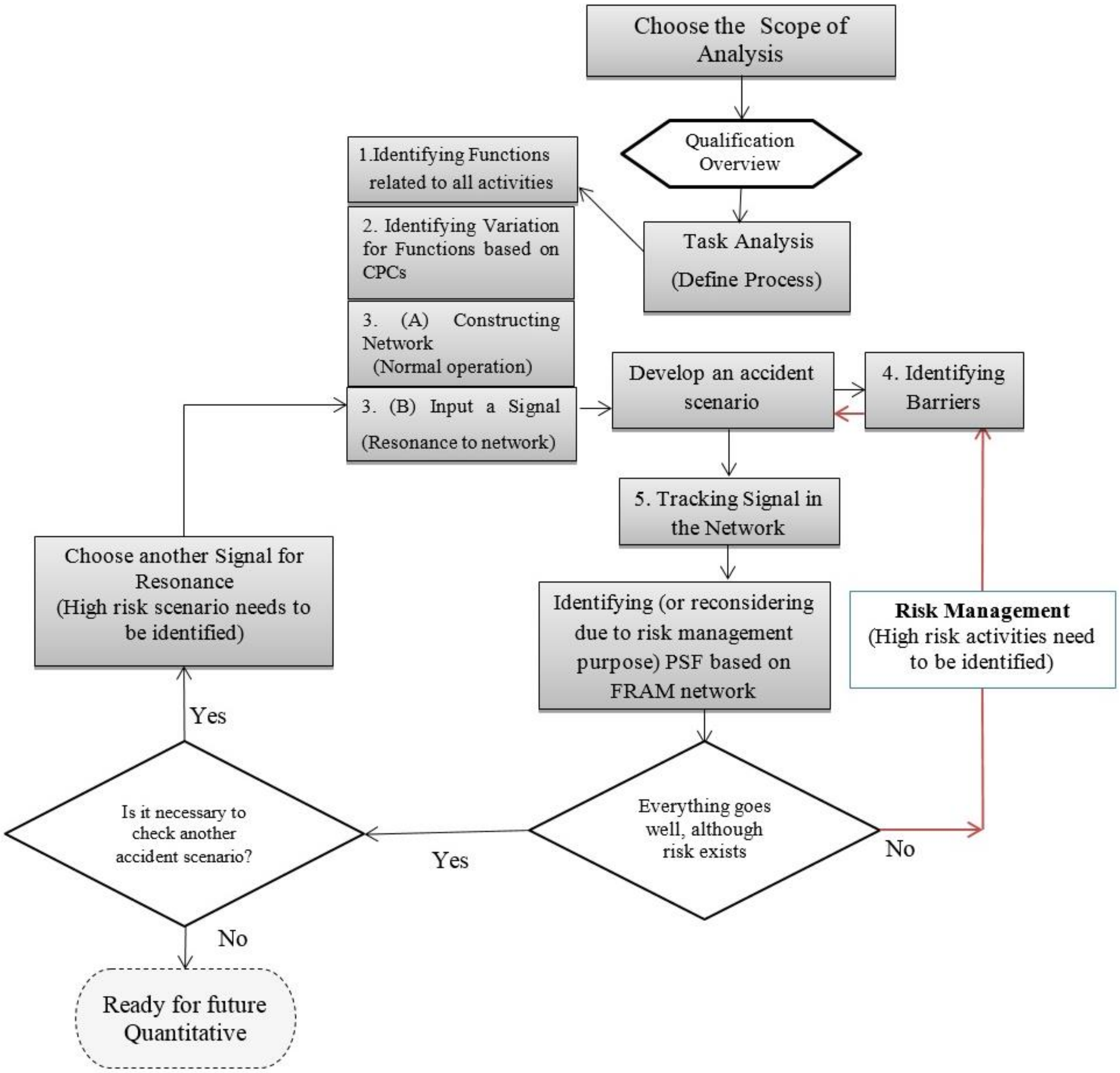

Fig. 2 Framework of a developed risk-based methodology for human error assessment

In the FRAM network for pre-maintenance presented in Fig. 3, the foreground functions are identified using a blue color and background function using green color. The resonance is a detectable signal that emerges from the unintended interaction of the variability of many functions in the network. The first function that the assessors want to impose a signal within is imperative, since they should track that signal through the network to work out realistic results. (If one provide wrong resonance may face up to exaggerated or wrong elicitation. This sentence is unclear). In this study, it is assumed that the first signal is derived from the earlier sub-activities of pre-maintenance, "prepare work" (Function No. 1 in Fig. 3).

Most of the functions in this study affected work conditions, competence, and stress and equipment variability. To better illustrate the track of the signal, each resonated function is numbered respectively with a red number and is highlighted in a reddish color to emphasize the resonance. Based on field studies and expert opinions, the most probable accident scenario following a human error in maintenance procedure of the pump would be a release of flammable liquid, meeting an ignition source, and the occurrence of a pool fire which can be extinguished only if a water sprinkler system is activated by a flame/smoke detector. Therefore these barrier functions are necessary to be identified for improving the safety of the work condition, explained in Table 2.

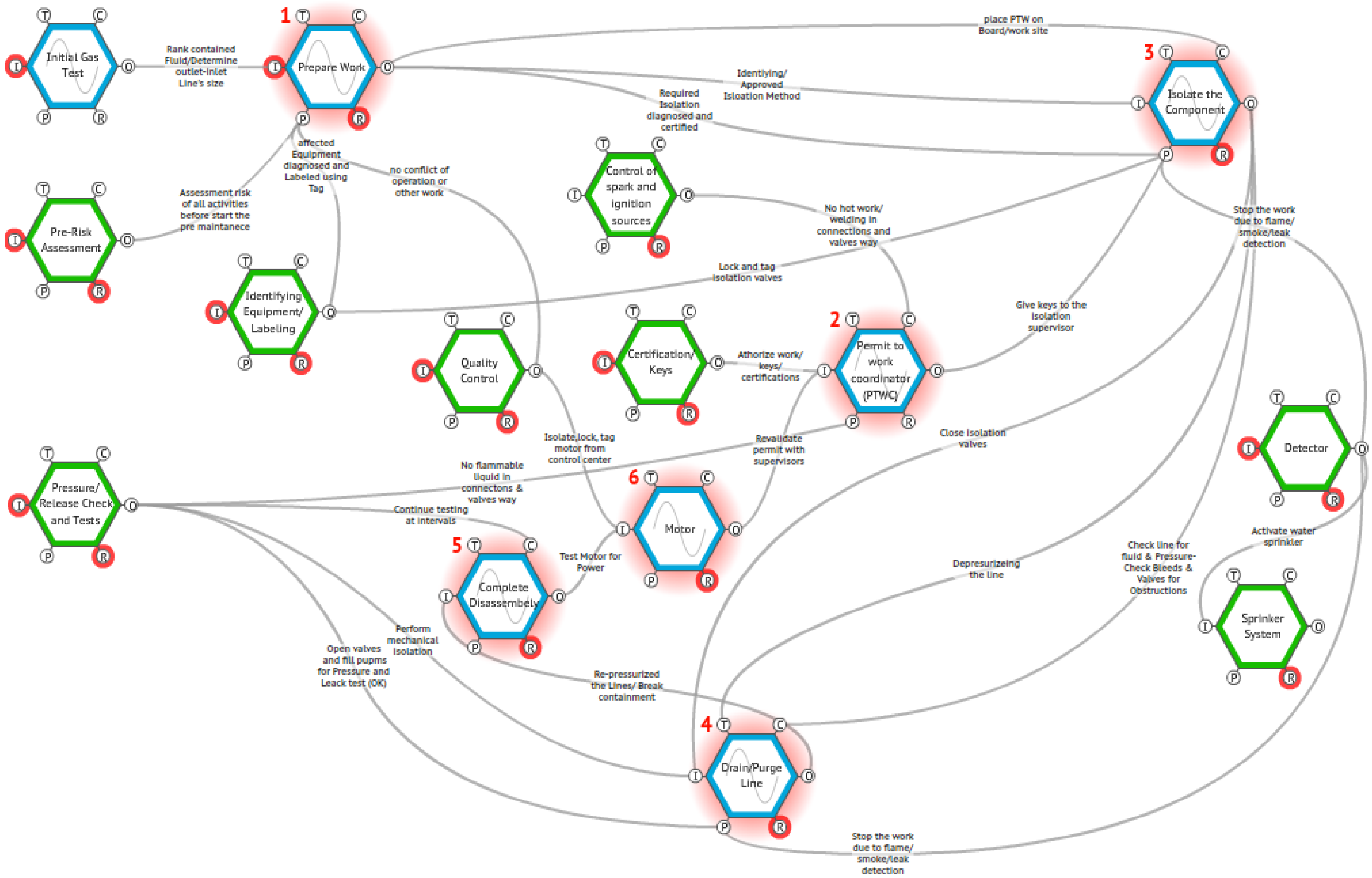

Fig. 3 A FRAM illustration for pre-maintenance of pump

The 'Detector' tries to stop the work due to flame, smoke or leakage detection (Step 4 in Fig. 2). Also, there is a possibility of failures in 'detector' or 'sprinker system'. The signal can then be amplified unexpectedly in FRAM by introducing more high-risk conditions, since one of the pre-conditions for 'Drain/Purge Line' cannot be satisfied and it means that function continues with fault condition. (for example condition where labor opens an isolated valve incorrectly, since it is not labeled before. if this malfunction appear as a pre-condition for function No.1 in Fig. 3in first stage, then the signal should be damped in next stages, to reduce total human errors during the operation. The same should be done for controlling ignition before issuing a work permit (Function No. 2 in Fig. 3).

Based on an event tree developed for pump maintenance risk analysis, one cannot define damping effects efficiently (See Step 4 in Fig. 2), since ET cannot provide nonlinear interaction between sub-activities at first glance. Additionally the quantification is based on the most probable accident scenario derived from field studies and expert opinion, therefore, other possible high risk accident scenario are unconsciously inevitable in ET (See Loops in 4 in Fig. 2). The methodology will provide a clear condition for monitoring risk and accident scenarios in a process to describe what may happen due to resonance of potential variability. In using this approach it is important to understand performance influence factors and causes that lead to accidents. This method can be regarded as the starting point of any quantitative assessment that previous researches use for their HEP analysis.

Table. 2 A FRAM module function description for pre-maintenance network (emphasizing Cold environment factors on functional variation)

Name of function	Drain/Purge Line
Type of Function	Foreground
Aspect	**Description of aspect**
Input	Close isolation valves Perform mechanical isolation
Output	Re-pressurized the Lines/ Break containment
Precondition	Open valves and fill pumps for pressure and leak test Stop the work due to flame/smoke/leakage detection
Resource	Tools, Area Technician
Control	Check line for fluid & Pressure Check Bleeds & Valves for Obstructions
Time	Depressurizing the line
Variability (answer to questions)	**1.** *Conditions leading to variations:* cold temperature, low visibility, ice ad-freeze, competence, availability of resources, time pressure **2.** **Complete disassemble** function will go wrong. The main errors stem from, Ice, fog, lack of solar illumination, stiffness of suit impairing movement, frostbite, inadequate measures in **Pressure and release check** function, wrong output from **isolate the component** function and failures in **detector** function **3.** The problem can occur in these conditions: Wrong valve closed or open unconditionally the wrong valve, although pre condition for test not satisfied but the task still continues and may be no heeds of the test result, tools are not available or may be out of order, no controls for the line and valve fulfilled, no detecting for flame or smoke that may lead to accident.

4. Conclusion

In this study, a qualification risk-based methodology is developed to improve the non-linear interactions in human activities for accident modeling, identifying possible barriers and improving the existing safety measures. A systematic methodology using FRAM was developed to investigate the role of human error in maintenance procedures of a pump. Application of this methodology shows that FRAM could provide high values to human errors that may help reduce risks arising due to human performances in each pre- and post-maintenance task. FRAM individually is based on resilience engineering that provides a good qualitative network to understand the condition in which a process can go right although it is faced with unpredicted risk. The developed methodology will be a turning point for studying interaction between nonlinear qualitative and quantitative based method in risk assessment to systematically identify human error in maintenance.

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