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Human Entropy (HENT) – A New Approach to Human Reliability Analysis

by

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Table of Contents

Nomenclature

ABS	American Bureau of Shipping
APJ	Absolute Probability Judgement
APOA	Assessed Proportion of Affect
ASEP	Accident Sequencing Evaluation Programme
CAHR	Connectionism Assessment of Human Reliability
CM	Control Mode
CMM	Capability Maturity Model
COCOM	Common Control Mode
CPC	Common Performance Conditions
CQA	Crew Quality Audit
CQI	Crew Quality Index
CREAM	Cognitive Reliability Error Analysis Method
CRM	Crew Resource Management
CRI	Crew Risk Index
DM	Decision Maker
Eb	Entropy due to Breach
Ec	Entropy due to Cognition
En	Entropy due to Negligence
EOC	Error of Commission
EOO	Error of Omission
EPC	Error Producing Conditions
ETTO	Efficiency Thoroughness Trade Off
FSA	Formal Safety Assessment
GFT	Generic Failure Type

GOMS	Goals Operators Methods and Selection Rules
GTT	Generic Task Type
HAZID	Hazard Identification Studies
HCR	Human Cognitive Reliability
HEART	Human Error Assessment And Reduction Technique
HEBC	Human Entropy Boundary Conditions
HENT	Human Entropy
HEP	Human Error Probability
HMS	Human Model Simulation
HRA	Human Reliability Analysis
HRMS	Human Reliability Management Systems
HSE	Health and Safety Executives
HyCs	Hypothetical Constructs
IMO	International Maritime Organisation
INTENT	Not an acronym
JHED	Justified Human Error Data
LTI	Lost Time Injury
MAIB	Marine Accident Investigation Branch
MCA	Maritime Coast Guard Agency
MERMOS	Method d'Evaluation de la Realisation des Missions Operateur pour la Surete
MFR	Mean Failure Rate
MMI	Man Machine Interface
NARA	Nuclear Action Reliability Assessment

NUREG	Nuclear Regulatory
PERT	Program Evaluation and Review Technique
PSA	Probabilistic Safety Assessment
R&D	Research and Development
SAFECO	Safety of Shipping in Coastal Waters
SCMM	Safety Culture Maturity Model
SLI	Success Likely Index
SLIM-MAUD	Success Likely Index Method
SMC	Safety Management Code
SMS	Safety Management System
SPAR-H	Simplified Plant Analysis Risk Human Reliability Assessment
THERP	Technique of Human error Rate Prediction
THFM	Tripartite Human Failure Modes
TRC	Time Reliability Correlation

List of Figures

List of Table

CHAPTER 1. Introduction of Research

1.1 Introduction

This chapter presents the quintessential aspects of this research, which includes a brief background related to the importance of shipping and the inhibiting factors that are associated with human factors in maritime operations. Therefore, articulated research problems, research questions, hypotheses, overall research aim and objectives are highlighted here in Chapter 1. In addition, the chapter also presents the thesis structure with details of how the thesis has been laid out.

1.2 Background

> *'In maritime industry, accidents and incidents are generally the results of error-fault chains, and many times it is difficult to identify the frequencies of accidents and incidents because of secrecy and inadequate history records'*(Arslan 2009)

On the whole, shipping is largely the most international and dangerous of all industries in the world in particular, hazards involve in chemical tanker operations (IMO 2002; Hetherington et al. 2006; Arslan 2009). Unfortunately, the safety records in the shipping industry are quite low and the industry is characterised by high consequence accidents and fatalities (Wagenaar and Groeneweg 1987; Rothblum 2002; Wang 2007). This is despite the advancement in design and stringent safety regulations (Van Urk and de Vries 2000). Accidents are often caused by quite a combination of complicated and simple events. In a study carried out on 100 maritime casualties, it was found that the generic number of causes of these accidents ranged from 7 to 58 (Wagenaar and Groeneweg 1987). In an effort to determine how these accidents happen, various studies were carried out by governments, academicians and industry stakeholders and the causes and effects of the maritime accidents were evaluated and categorised. The study revealed that of all the causes, human factor human factor is the dominant cause of accidents (Reason 1997; Rothblum 2002; Youngberg 2003; David 2005; Wang 2007)

Human error is universal in the sense that, ‘all humans make errors’ (Harrald, et al. 1998). There have been numerous attempts by different scholars to expound human error yet, because of the differences in viewpoints and intended application no universally accepted standard yet exist (Lenné et al. 2010). In the maritime environment, studies have indicated that human errors contribute largely to groundings, collisions and on-board fires with following percentages (Bryant 1991; Club 1992):

- Over 75% of all maritime grounding accidents
- Over 89% of all maritime collisions
- Over 70 % of all maritime fires and explosions

The shipping industry is continuously expanding and today has registered shipping fleet in over 150 nations worldwide (Parola and Veenstra 2008; Eyring, Isaksen et al. 2010). Technology has advanced system design with diverse and redundant layers of defences, barriers and safeguards to prevent failures; the concern for safety is however, on the increase. Reductions in accidents due to hardware equipment have unveiled the underlying level of human disorderliness as the precursor for accidents.

The Maritime industry is comprised of multi-complex systems, and these systems require endurance and high reliability to withstand long operational periods in isolation, at sea. The maritime industry continues to suffer losses of material goods, equipments and have higher fatalities than any other industry. In 2006, Al Salam

Boccaccio 98 sank causing over 1,000 fatalities and the generic cause of the accident was attributed to gross human factor. There was negligence in maintenance, master incompetence and lack of compliance to rules and regulations. The master made no effort to send a distress signal, did not try to return to port when fire broke out, and did not order the crew or passengers to use rescue systems (Lloyds List 2010)

Many criticisms and testimonies were made on the non-adherence to safety standards in the maritime industry. The recent BP oil explosion in the Gulf of Mexico has been described as one of the worst environmental pollution in the world. It was widely reported that the BP Oil disaster involved human element in the chain of events that led to the disaster, to the extent that the management of BP described the incidence as "*a complex and interlinked series of mechanical failures, human judgements, engineering design, operational implementation and team interface*"(BP 2010). Various reports indicated that, the BP mishap was generally alleged as a result of a complex and interlinked series of human errors and failures (Timmer 2010) .

The International Maritime Organization (IMO) is the United Nation's (UN) specialized agency with responsibility for the safety and security of shipping and prevention of marine pollution. The IMO has been taking stern measures to address safety issues and have promulgated policies to this effect (IMO 2009). The IMO promulgated the Formal Safety Assessment (FSA) to fit with risk assessment initiatives with a view to provide support for decision making (IMO 2002). The progression of FSA methodology, which is shown in Figure 1:1, is a rational and systematic process for assessing risks relating to maritime safety and the protection of the marine environment. The FSA is also used for evaluating the costs and benefits of the options available to the IMO to reduce these risks. Efforts made in risk mitigation and reductions through the FSA are also constrained by the concept of *As Low as Reasonably Practicable (ALARP)* and cost effectiveness.

The philosophy of FSA/ALARP implies that certain risk is tolerable because of cost implications (Guarin et al. 2009). The ALARP declaration poses some fundamental questions and indirectly, legal controversies on what is tolerable and to whom are the risk tolerable? (Thomas 2008). That notwithstanding, most of the IMO safety regulations are reactive and based on ad hoc response to mishaps (Knudsen and Hassler 2001; Psarros, et al. 2010). The comparatively high rate of fatalities in the maritime industry compared against other industries highlights the need for specific research on the matter. Even though ships fulfil the some of the IMO requirements, the crew on board are still subjected to some inconveniences such as; hazardous noise, vibration etc which affect performance (Turan et al. 2010).

Maritime accident databases have primarily been generated by various stakeholders but because there is no standardised reporting system it has been very difficult to elucidate the causal themes

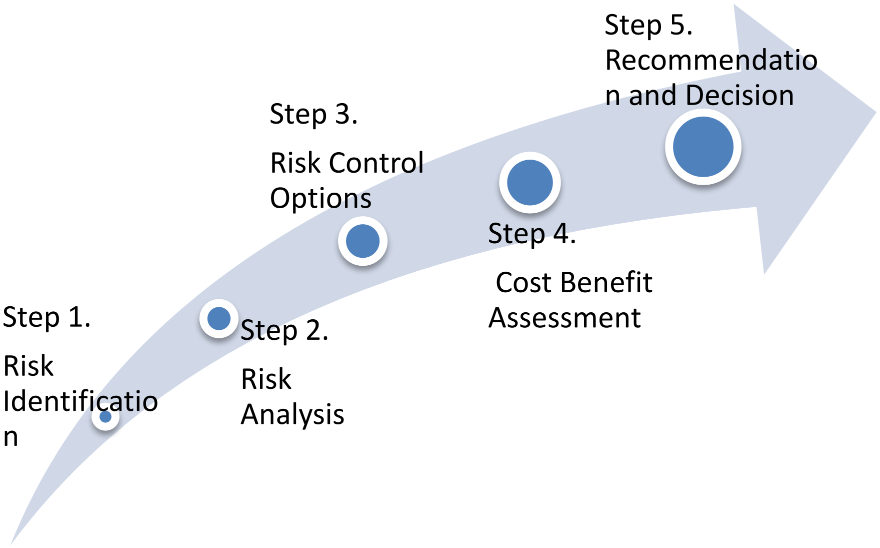


Figure 1:1- Formal Safety Assessment Methodology for Risk Analysis

Unfortunately, the accident reporting models were also found to be lacking in details (Rasmussen 1998; Schröder-Hinrichs, et al. 2011). However, in a more general sense, in-depth analyses reveal that most of the causal factors are human errors. The taxonomy of maritime accidents by causation factors reveals the trends and failure modes, which clearly indicate human contributions to failure as shown in Appendix 1-1 (Baker and Seah 2004). Results from the American Bureau of Shipping (ABS), the Canadian Transport Safety Board (TSB), the Australian Transport Safety Bureau (ATSB) and the United Kingdom Marine Accident Investigation Branch (MAIB) are in agreement that human factor is the accident precursor. The human contributions to maritime accidents were given in percentages as; ABS = 85%; TSB =84%; ATBS = 85% and MAIB = 82%. Therefore, to understand failure modes, accident models should be all encompassing, reporting behaviour shaping mechanisms, work constrains and boundary conditions which shape acceptable performance (Leveson 2004). According to Reason (1997), unsafe acts are as a result of local factors, which often combine with natural human tendencies to produce errors and violations.

However, as there are many different human temperaments, characters, customs and ways of thinking, these differences can arguably shape human performance. Human system endeavour, which can cause failure or accidents, can be evaluated in various stages of product development, through operation, to de-commissioning. Unfortunately, human-system interaction is unavoidable, as the use of automation to augment or supplement for human involvement has thus far been without success. Table 1-1 summarises the strengths and weaknesses between human operator systems and automated systems (Bainbridge 1983; Victor and Parasuraman 1997). Although different persons may cause different failures and are unlikely to commit the same errors repeatedly, data on human error is still useful for pattern identification and guidance for the risk analyses.

Table 1-1: Human Operator versus Automated System

Human		Technology	
Strengths	Weaknesses	Strengths	Weaknesses
Can apply judgment	Inconsistent	Consistent	No judgment
Adaptable	Subject to errors	Predictable	Cannot be programmed for all eventualities
Can apply wisdom and knowledge	Unpredictable and possibly unreliable	Efficient	No sentient knowledge
Interactive	Subject to emotion and motivations	Uniform and reliable	Constrained by human limitations in design, installation, and use

The concerns for human factors cut across all industries and while some high precision industries have advanced in Human Reliability Analysis (HRA) modelling to control human error. There is however, a gap in the coverage of HRA technique for mobile systems, in particular maritime and offshore systems (Eleye-Dotubo. 2008). Thus, this study explores the human factor in maritime operations to develop a human reliability model for improvement of safety in maritime operations.

Prediction and control correlate to system resilience against dysfunction and subsist even when things go wrong. Knowledge of system characteristics such as structure, processes and procedures, robustness and redundancy etc. enable its operational behaviour to be predicted in a range of circumstances. Thus, Probabilistic

Risk Analysis (PRA) is a strong tool to quantify or predict uncertainties in various institutions and organisations to carry out account safety audit. PRA is often referred to as Quantitative Risk Analysis (QRA) or Probabilistic Safety Assessment (PSA), in each case, organisational or systems risks of failure or probability of success are predicted and this concept has been proven by different analysis (Guarin et al. 2009). Both Risk and Reliability (R&R) are probabilistic entities; Risk is measured as a function of scenarios, probabilities and consequences (Kaplan, et al. 1981).

$$\text{Risk} = \text{f (Set of } \textit{scenarios } n_i\text{. } \textit{Probability } P_i \text{ and } \textit{Consequence } K_i\text{)}$$

Reliability is a measure of chance/probability that the intended function can be sustained successfully for a given period of time or routine circumstances' and is a binary continuum measured between zero and unity. By this definition, reliability has four parts namely; probability, intended functions, time and condition. QRA is increasingly applied in most sectors of human endeavour, including aviation, shipping, railway, health sector, construction, finance, power plants and chemical plants. QRA techniques are employed as a prerequisite for regulatory frameworks by governments, private enterprises and stakeholders, all with a view to manage risk and guard against undesirable consequences (Bedford and Cooke 2001).

To date, different industries and organisations have developed unique trends in risk management, each with its merit and demerit depending upon precision requirement; scope cost element and the severity of perceived risks. In Science and Engineering, QRA is carried out to determine systems vulnerability to risks or chances of failure through inspections and by antecedents utilising:

1. System or component failure rates.

2. Documented evidence and the work experience of personnel.
3. Critical assessments of design constraints and factors of safety.
4. Human system interface in operations such as ergonomics.

Humans are an intrinsic aspect of technological systems with regards to design, manufacture, maintenance and operations. We make good and bad choices, and in our endeavours, humans persist on success and guard against failure. However, very often experts manipulate events to a favourable outcome even when risks are perceived, This attitude can be exhibited through middling with technological systems procedures, rules, management systems, training, inquiries, reward and punishment (Duffey and Saull, 2008). Human beings take risks in all endeavours in gamble, trade, and design, maintain or operate a technological system etc. According to the *risk homeostasis theory,* humans have the tendency to take compensatory risk once an existing risk is reduced or eliminated by design improvement (Taylor, 2001). To understand and anticipate appearances of risk, this research seeks to explore and find out:

- How to predict what the next mishap may be and when it may occur?
- How to measure, remove, manage or reduce future risks?

It is essential, therefore, to be able to predict the outcome of an undesirable event, for example in technical components or systems. In order to improve performance and facilitate learning, it is important to explore pre-existing common knowledge from experience in mishaps. QRA initiatives exist to quantifying risks and to develop strategy to manage or isolate each element of risk (Montmayeul et al. 1994).

Quantification of risks in human system interface is known as Human Reliability Analysis (HRA). A result obtained from the HRA is input into PRA for safety audit purposes. The human reliability is incorporated into the PRA due to incessant human contribution to failures (Mohaghegh et al. 2009). Humans represent the largest contribution to system failure with an estimated percentage of more than 80% (Kirwan 1994; Cacciabue 2000; Barrett 2005). While some high risk industries such as nuclear and aviation have developed high precision and robust QRA tools, industries such as the maritime industry are still lagging in this safety management initiative, and as a result fatalities continue to occur within the industry (Bai 2003; Uchida 2004; Wang, 2007).

Human Reliability Analysis (HRA) has its roots in the study of human performance due to incessant system failures; the initiating events of which were caused by human elements. HRA was first incorporated as part of the final version of the WASH-1400 study on nuclear safety (Rassmusen, 1975). The technique was then restricted to the analysis of failure probability for tasks due to a human element. The human error probability was defined as the probability that an error occurs when carrying out a given task (Bedford and Cooke, 2006). Consequently, other industries have followed suit, and reviews of accident reports indicate that human factor can be identified as the root cause of most accidents (Kletz 1999; Wang 2007). Most HRA techniques obtained their data from research conducted in experimental psychology and behavioural sciences; the data was then used as the foundation on which HRA models were built (Gertman and Blackman 1994). To minimise the probability of failure, human factor is accounted in PSA for reliability analysis. Therefore, the purpose of HRA is threefold:

1) Render inventory and description of human contribution to risk known as Hazard Identification (HAZID). This includes, but not exclusive to risks identification, risks ranking based on severity and frequency and identification of causes of risks.

2) Develop a Model for Quantification of Human Error (HRA tool)

3) Identify ways to reduce the risks through risk-based design, review of management policy and enabling international regulatory bodies to develop rules and guidelines

Currently, there are over 40 HRA models for estimating Human Error Probability (HEP) and each has its own merits and drawbacks (Isaac et al. 2002). The HEP model takes into account as many factors as the designers of the model thought desirable. The models are also restricted to:

1) The designer's knowledge and experience of the system

2) The nature of the system and organisation being studied

3) The degree of accuracy and comprehensiveness required

HRA methods tend to fit the randomness and ambiguity of human actions in terms of design, manufacture, maintenance and operations, but the models still need further validation as well as refinement of the context in which they are to be used.

1.3 Thesis Structure

The general structures for this research study are summarised as follows:

Chapter 1: Introduction

Chapter 1 provide a complete overview of this research study. The chapter discusses the background of the study.

Chapter 2: Aims and Objectives

This Chapter highlighted on the research problem and the overall aims and objectives.

Chapter 3: Critical Review

In chapter 3, review of maritime accidents was carried out and then critical review on safety and risk analysis methods. The critical review covers existing practices in human reliability analysis across various industries. The advantages and disadvantages of all the HRA models reviewed are highlighted. In general, overall assessment of current practices was carried out and weigh up against maritime industrial requirement. The critical review illuminates existing gaps and associated constrains through which the contributions of this research work were developed.

Chapter 4: Framework of Approach

Following the critical review in chapter 3, the framework for the research methodology which was developed was discussed in chapter 4. The methodology provides an outline on how the research aims and objectives can be achieved.

Chapter 5: Data mining

Chapter 5 covers data mining. In this chapter the rationale for data mining on human factor are discussed. Various data mining techniques were investigated with a view to identify a requisite technique that is most befitting to this research work. Pros and cons of the data mining methodologies are provided and the rationality for the methods used in this research work are also highlighted. Details of the procedure and results obtained from the adopted techniques are also presented in this chapter.

Chapter 6: Quantitative and Qualitative Analysis of Results

Chapter 6 provides qualitative and quantitative analysis of the data obtained from the previous chapter. The subjectivity and nature of human factor necessitates the quantitative analysis because human factor is wide and complex. So, any information obtained must be interpreted accordingly to understand the meaning of the figures before they are turned into working solutions.

Chapter 7: Research Findings

The quantitative analyses replicate the data variables mathematically and statistically, providing justifications. Therefore, in this chapter, the results are aggregated using different statistical techniques and highlights how and why each method was used with worked examples. The mathematical analysis identifies the pattern of human disorderliness and was used to develop the framework in which the failure modes are classified. The chapter also demonstrates how the reliability utilities such as crew quality variables can be used to measure crew quality index.

Chapter 8: Human Entropy Model (HENT) - Concept and design

Chapter 7 builds upon the qualitative and quantitative analyses in chapters 5 and 6 to present the research contribution i.e., the human reliability model which is called Human Entropy (HENT) for maritime application. In this chapter the proposed modelling concept is presented including its usage and application. The computational resources which provide the frame work of analysing man-machine interface are also explained. An outline for mitigation of human disorderliness is also presented.

Chapter 9: Case Study and Application of HENT Model

In order to gauge the performance and demonstrate the designed maritime human reliability model, a practical case study was undertaken and is presented in this chapter. The case study was conducted on Crew Quality Audit (CQA). The CQA provides a comprehensive inventory of personnel capability by identifying each crew reliability and risk index.

Chapter 10: General Discussions and Recommendations

In general, this Chapter amplifies the HENT modelling concept and demonstrates how the model can be utilised to achieve the desired safety in operations. Having highlighted how complex human factor can be, and the changing technological advancement, human reliability analysis utilities are inexhaustible.

Chapter 11: Conclusion

This Chapter presents the overall conclusion on this research study and highlights the research benefits and achievements.

CHAPTER 2. Aims and Objectives

2.1 Research Problems

The inhibiting factors facing human reliability analyses which have been considered to a large extent in this thesis are:

1) While high consequence accidents are attributed to human factors, there is currently, no accurate taxonomy of human failure mode and generic root causes of failure that limit the crew capability and functionality.

2) Lack of credible calibration data for human reliability analysis rendered most of the HRA efforts fictitious. The existing data bases do not represent all cases of human-system endeavour and the sources of such data are either conflicting, disputed by those involved or fail short of root cause.

3) Behavioural scientists have succeeded in bringing forth Performance Shaping Factors (PSFs) into the domain of HRA. As a result, the behavioural scientists have dominated the study in human reliability analysis even when it involves technical systems. And due to the complex nature of the technical systems involve, the behavioural scientists could not provide accurate taxonomy and praxis of the PSFs which could be seen through practical systems thinking and needs for bounded rationality.

4) Lack of flexibility and functional HRA models which could take into account underlying reasons for human disorderliness as well as crew needs and limitations.

5) Most of the HRA are qualitative and lack the analytical rigor needed to mitigate and improve design for safety especially in safety critical operations. Although, HRA models need to be partly subjective, quantitative appraisal enable accurate design and operational adjustments.

2.2 Research Questions

This research work was initiated by the following questions:

1) What are the risks associated with in maritime operations and why are over 70% of accidents due to a human's factor?

2) What are the unique characteristics of maritime operations as compared to other industries?

3) What HRA model could be most appropriate for maritime application?

4) How will the maritime HRA model be used to mitigate and minimise occurrences of failure and strengthen detailed design knowledge with reference to human performance?

2.3 Aim of Research

The aim of this research work is to develop a Human Reliability Analysis model specifically for marine and offshore operations which can be used to reduce failures and accidents due to human factors.

2.4 Research Objectives

In general, the purposes of Human Reliability Analyses (HRA) are: To identify risks due to human system interactions, quantify human risks of failure and develop a means of reducing or eliminating these risks. Therefore, the objectives of this study are:

1) Carry out comprehensive appraisal on maritime accidents; identify and establish the underlying factors involved in the causation of accidents which are constrain to safety. This will be done anonymously through interviews/questionnaire and rigorous subjective analyses. Accident data bases from private, regulatory agencies and governmental various organisations will be interrogated.

2) Investigate existing risks in maritime in maritime operations, analyse and quantify the main common accident underlying reasons in particular, the human elements. This will include identifying the onboard non-compliances to safety standards due to bounded rationality and short cuts. A Catalogue of relationships between accidents and underlying reasons will be established.

3) Explore probabilistic insight into human element risk reduction technique in maritime operations. This includes; provision of utilities that can increase conceptual thinking for resiliency and adaptability to environmental criticalities.

4) Develop a novel human reliability analysis (HRA) model for maritime operations to improve safety. The proposed HRA model will support operational adjustment to sustain systems persistence in critical situations and strengthen detailed design knowledge with reference to human performance at sea.

5) The proposed HRA model will have capability to support training needs such as crew resource management and be capable of providing scenario driven analysis to compute risks at varying operational conditions.

2.5 Contribution to Knowledge

This research study seeks to cover gaps in the domain of human reliability studies by contributing to existing knowledge and practices in safety enterprise as follows:

1) A novel HRA technique will be developed specific for maritime applications. This will facilitate and strengthen detailed design knowledge with reference to human performance at sea by generating missing quantitative knowledge through performance appraisal.

2) Qualitative and quantitative taxonomy and praxes of Performance Shaping Factors (PSFs) for maritime operations were developed. The generic operational boundary conditions for man machine interface were explored to provide requisite organisational resilient structure in operations.

3) Exposition of and taxonomy of human failure modes in maritime operations. In this case, *tripartite* human failure modes were uncovered (cognitive error, negligence and breach). The evolution of *tripartite* human failure modes explores and introduces *Human Entropy* (HENT) which a detour to Human Error (HE). This revelation will continue to expand the scope and horizon of HRA to achieve accurate safety audit tool.

4) The qualitative and quantitative results from HENT modelling technique introduces a new concept for reporting human reliability using complex plane.

The concept of complex plane is to enable clear definition of (quantifiable) real and unquantifiable (imaginary) variable utilities.

5) The HENT model will be suitable for use as a practical tool for crew resource management to increase human feasibility, cognitive awareness and facilitate crew and management resiliency. Thus, functional thinking will be enhanced by taking into account the underlying reasons for human disorderliness in operations as well as the crew needs and limitations

6) The HENT tool can be used to develop risk-based design for safety. This will enable designs that will potentially address the risks resulting from human disorderliness such as corner cutting, trade-offs extraneous acts etc. The HENT model can be used as a tool to exploit frameworks for future Research and Development (R&D).

CHAPTER 3. Critical Review

3.1 Introduction

This Chapter reviews Maritime accidents, critical review on safety and risk analysis methods. The advantages and disadvantages of current HRA models were analysed with a view to expunge existing gaps. The chapter reviews thirteen major Human Reliability Analysis (HRA) techniques used for Probabilistic Safety Assessment (PSA). Other key issues discussed in this Chapter include; Pattern of human error, human error data, modes of quantification and limitations. PSA is a judicious and systematic way of investigating, predicting and reporting quantitative state of readiness or circumstances of systems to function without failure or disturbance (Montmayeul, Mosneron-Dupin et al. 1994; Guarin, Konovessis et al. 2009). Human Reliability Analysis (HRA) came into the limelight in the study of human performance in design, manufacture, maintenance and operations (Mohaghegh, Kazemi et al. 2009). HRA is a "*method employed to quantitatively assess the impact of potential human errors on the proper functioning of some system composed of equipment and people"* (Swain, 1990). Human reliability requires broad analysis which must involve the use of qualitative and quantitative techniques to measure the human contribution. Human Error Probabilities (HEP) are the probabilities that errors may occur in executing a detail or task. The HEP is often quantified as (Kirwan,1992):

$$\text{HEP} = \frac{\text{Number of errors occured}}{\text{number of opportunities for error to occur}}$$

Human error manifests throughout the life cycle of a system both in design, production and maintenance or in operations as depicted in Figure 3:1

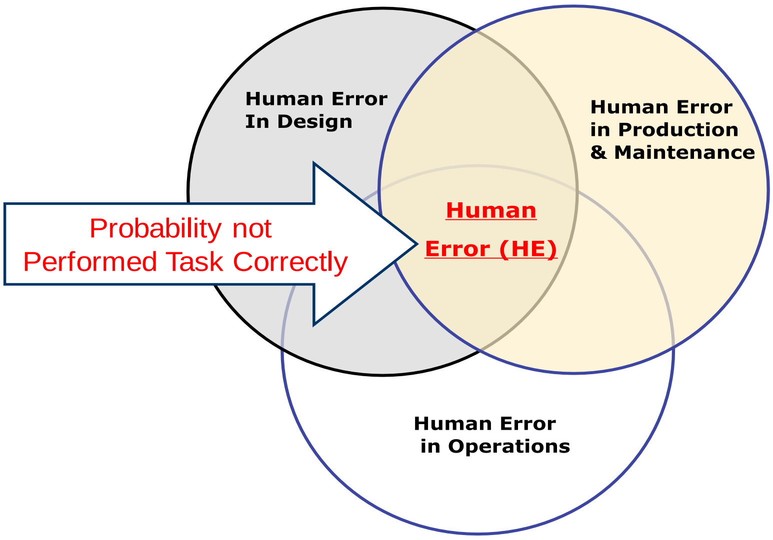


Figure 3:1 - Categories of Human Performance

3.2 Maritime Accident Statistics

Customarily, safety as precautions is exercised and practiced by every organisation because of apprehension of undesirable events. Similarly, safety is mitigated in design and by regulatory bodies' regulatory bodies such as the International Maritime Organisation (IMO) based on proven experience to set sight on prevention of mishaps. As the maritime community has realised that despite all the increased safety standards and technological developments accidents are still not being prevented as can be seen from accident statistics in Table 3-1 which shows frequency of occurrences per type of accident. It is equally important to note the pattern of failure by identifying which of these categories of accidents has the highest frequency. From all the accident data bases, it was clear that collision and fire are the main competing accidents. For instance, Figure 3:2 shows the relative occurrences of various types of maritime accidents (merchant ships) in which collision top most. Figure 3:3, shows the relative occurrences' of accidents type from a military data. Therefore whilst, the military are susceptible to fire incidences the merchant ships are prone to collision/contact. In a similar study, it was observed that collision contributes to 89- 96% of all the maritime accidents (Rothblum, 2002). Collision/contact is a result of so many factors and the trend is seemingly universal. The data in Figure 3:2 was for United Kingdom while the data in Table 3-2 were obtained from Hong Kong and both indicated Collision with highest frequency of occurrence (IMO 2010). Other relevant maritime accident statistics are shown in Appendix 3-1.

Table 3-1: Occurrences ‘of Maritime Accidents by Types (Courtesy MAIB)

Period	Recorded No. of Accidents over the period	Type (category) of Accident	Frequencies of occurrences over the period
2009 January – February	8 (2 months record)	Collision - Capsize -	4 1
2008 January - November	15 (11 months period)	Collision- Grounding - Fire - Flood -	2 2 2 1
2007 January - December	16 (1 year period)	Collision - Capsize - Fire - Design -	5 4 2 5

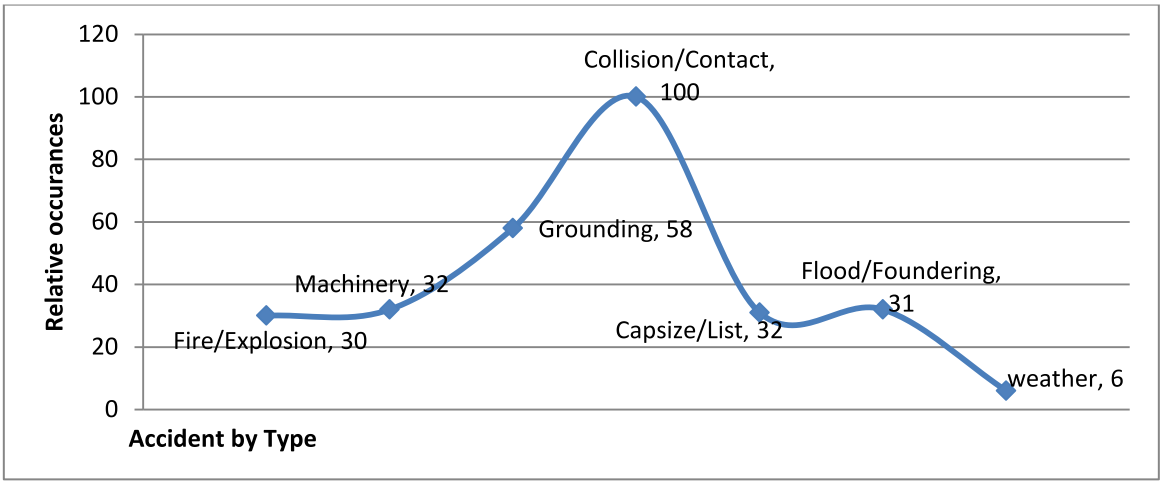


Figure 3:2- Relative Occurrences of Types of Accident over 10 years (Merchant Ships)

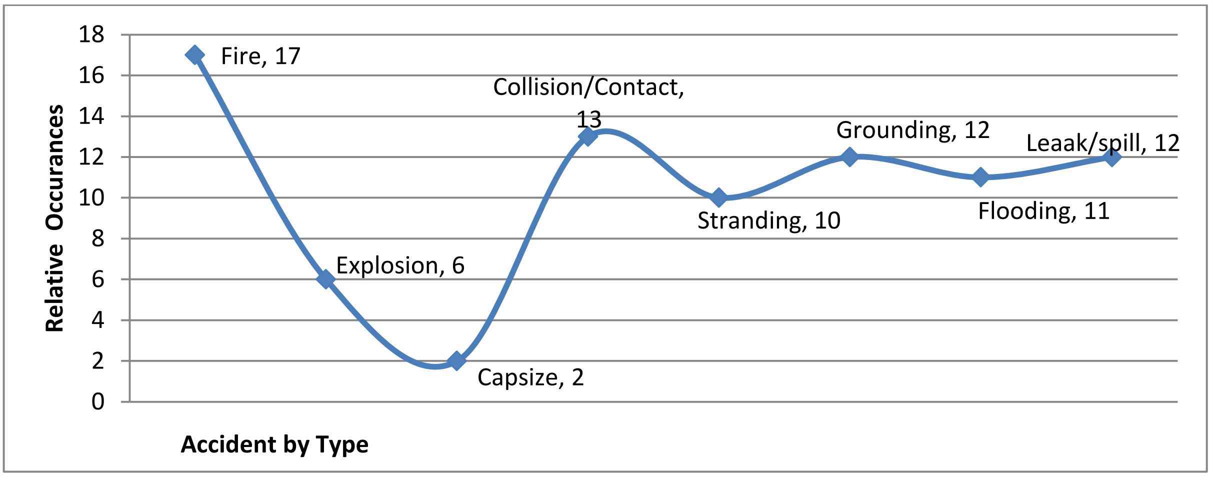


Figure 3:3 – Relative occurrences of Accident by Type (Military Ships)

Similarly, Figure 3:4 show variations of maritime accidents by type of ship. The data shows that while most accidents occur with General cargo ships, Gas tankers have the least number of reported accidents. One can deduced that, the Gas tankers exert more safety line of attack which may be attributed to potential dangers or threat to the huge investment and impact in the event of any disaster. Similarly, one can assume that the crew and management of the Gas tankers are more prudent to safety while, in general cargo vessels safety is a secondary issue which can be breached or neglected?

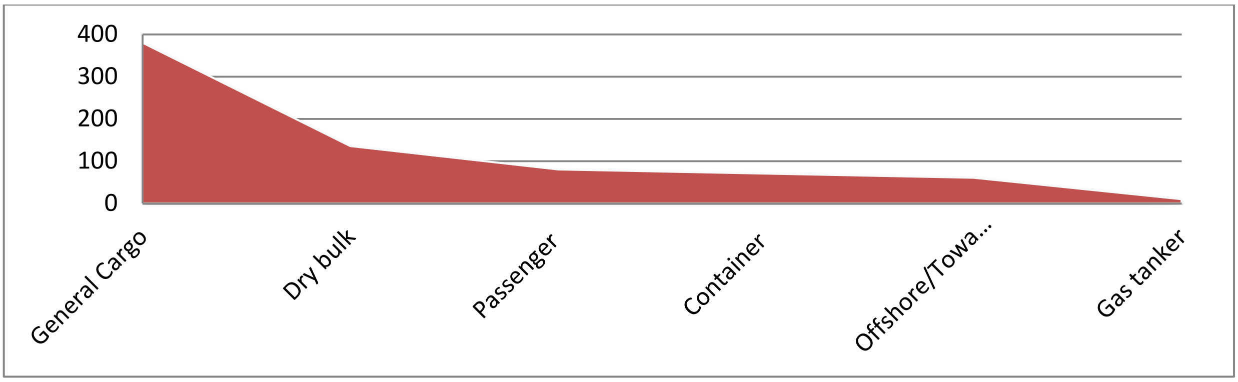


Figure 3:4 –Relative occurrence of Accidents by Type of Ship over 10 years

These Maritime accidents are not without losses of material and adverse environmental impact but, seldom accompanied by high fatalities as shown in Table 3-2 and

Table 3-3. Though, the rate of accidents differ from one region or flag state to the other but, the trend is almost the same; high failure rate and high human contribution to accidents.

Table 3-2 - Accidents Statistics 2009 (Courtesy MAIB)

Types of Accident	Within Hong Kong Waters				Outside Hong Kong Waters			
	No. of Cases	Fatalities	Persons Injured	Persons Missing	No. of Cases	Persons Killed	Persons Injured	Persons Missing
Collision	159	1	32	-	48	6	1	17
Contact	42	-	2	-	17	-	-	-
Stranding/Grounding	36	-	2	-	15	-	-	-
Foundering/Sinking	26	-	7	-	3	-	-	-
Fire/Explosion	29	-	2	-	16	6	2	1
Capsized/Listing	11	2	4	-	-	-	-	-
Others	29	-	-	-	5	-	-	-
Total	**332**	**3**	**49**	**0**	**104**	**12**	**3**	**18**

Table 3-3 - Number of Ships Lost (Courtesy, IMO)

Year	**2006**	**2007**	**2008**	**2009**	**2010**
Ships of 500 GT and above	88	91	80	2009	119
Ships between 100 and 499 GT	32	44	55	44	53
Ships of 100 GT and above	120	135	135	142	172
Loss rate (all ships)	1.3	1.4	1.4	1.4	1.7

Analyses of accident statistics within the maritime industry have indicated that most of the accidents are neither due to technical failures nor due to influence of weather conditions but, due to human endeavour in the form of negligence, error and breach of safety standards (El-Ladan and Turan 2010). It is also a common knowledge that in most accident reports, the word '*I assume*' features in most of the reports in various forms:

1) I assumed that the ramp doors were closed after loading the vessel
2) The management assumed that the ship can be managed to the next port
3) I assumed that the trainee knows the right valve to open
4) I assume the incoming watch knew about the ongoing maintenance job
5) I assume the other ship will give way
6) I assume watch keeper is not over stretched

7) We (management) assume that we can make some savings by skipping maintenance schedule

And so on and so forth. As these catalogues of assumptions prove vague, accidents will win through. The fact is, humans are the users and the crew are not part of the design of the vessel and the system. Crews may not have knowledge on the design intrigue of a system on board his vessel, but can reduce/eliminate the risk of an accident by conscientiously ensuring regular equipment maintenance, test operation, training and reporting whatever is appropriate. Most of these issues fell short of what is vital and essential in human endeavour as will be seen in accident reports. Furthermore, it has been often ignored that the human has not been evolving the way that technology is developing and the physical capabilities and the limitations of the human is being overlooked. Addressing the human element in practical ship design and operation is a challenging task due to the traditions, lack of knowledge and most importantly the cost.

Accidents attributed to human error have been closely analysed by governmental organisations as well as many researchers. Common well known human factor problems are well identified however the findings of the studies conducted by different researchers or studies based on different accident databases tend to contradict each other. This is because taxonomy of error and its manifestations are not so articulated because of complexities in legal tussle. Such complications in marine accident data bases can be seen even from some historic maritime accidents as shown in Table 3-4, and Table 3-5 (classified data). The root cause of accident can be compound with '*multiple*' sources, especially since most of the accidents are due to human flaws.

Table 3-4 - Historic Maritime Accidents

Vessel/Platform	Influencing Factors -	Fatality/Consequence	Root Causes
MV *Don Paz, 1987*	Logistics, Crew quality and Training	Over 4, 000	Violations of safety by Management and Crew Negligence in look out
Al-Salam Boccaccio	Logistics, Training, Procedure and Communication	Over 1000 Fatalities	Lack of maintenance and capable crew to communicate and carry out fire fighting at distress
Piper Alpha, Ocean Ranger	Communication and Supervision	167 Fatalities	Communication gap after maintenance and non observance of Start/Stop procedure
Herald of Free enterprise	Communication, Crew efficiency and Procedure	194 Fatalities	Speeding above standard and negligence to close ramp door after loading- procedural breach
Exxon Valdez oil	Crew efficiency and Stress	40 Million litres crude oil spill	Master was drunk and Crew stressed
Braer	Logistics, Crew quality	Vessel grounded	Negligence of duty by Captain and watch keepers to keep. Design issues can also be addressed in bridge watch keeping.
Amoco Cadiz	Weather, and Communication	Loss of over 1.6 million barrels of oil and the vessel. Both vessels and oil worth more than US$40	Weather accompanied by communication bureaucracy between Captain

		million.	and ship owners to rescue ship in good time.
Ocean Ranger	Weather and Training	84 Fatalities	Weather and inability of crew to de-flood tanks
Estonia	Controversial	852 Fatalities	Weather blamed and military hardware
Aka BP Oil Spill	Management in ability to provide requisite logistics	Rated as one of the worst oil spill. 16,000 miles of coastline was affected, over 4.9 million barrels of oil spill within 87 days and accompanied with death of 11 crew, and over 1,000 animals.	Corner cutting for profiteering, negligence

Table 3-5 - Classified Accident Data per Type and Generic Root Causes

Type of Accident	Consequence	Year	Generic root cause	Remarks
Collision	Destroyed jetty	1994	Captain Error	Violation of regulation (entered harbour without Tug)
Grounding	Ship’s Hull destroyed	1995	Stranding	Negligence (Loss of Control, operators exhausted Air)
Grounding	Propellers and Rudder badly damaged	1997	Over speed peed	Negligence
Fire	Destroy funnel and canvas	1996	Engine started with exhaust manifold in close	Negligence (safety procedure not observed).

			position	
Explosion	4 Fatalities	1998	Leak of Toxic gases	Operators Negligence (refused to observe safety while handling sewage plant)
Grounding	Fatigue	2002	Fatigue/stress	Cognitive error (crew forgot to observe sounding)
Collision -	Destroyed ships superstructure	1996	Weather	Captain Violation and operators negligence (disobeyed weather focus and entering harbour routine).
Explosion	One Fatality	2005	Explosion of Turbocharger due to oil leak	Negligence (maintenance team did not tightened chamber cover well.)
Fire	Material destruction	2006	Welding upper deck without sentry	Violation (procedure violated)
Crash to jetty	Damage to ship’s bow	2008	Procedure and training	Captain Negligence (procedure training)

In current accident databases information is being recorded for what people reckon to be the most obvious accident factors. However it can be argued that the underlying factors which are really causing the accident are not quite clear, and is the result of the confusing situation described above. A typical example of this can be observed from the MAIB’s accident report database. For over 19 years of information, noise as a contributing factor to accident was reported in only 2 occasions (Turan et al. 2010). When is compared from the results in the latest research on effects of noise on crew, the comparison between realities and databases are contradicting.

Similarly, the analysis of 100 maritime accidents carried out by Dutch shipping Council makes an interesting study (Willem et al. 1987). It was uncovered that, a total number of root causes are 2250; meaning, on average, over 22 possible causes per accident. Astonishingly, 96 out of the 100 cases could have been put up by those involved, but did not. Table 3-6, shows taxonomy reviewed 100 accidents with corresponding number of errors and erring crew(s).

Table 3-6 - Human Errors and Erring Crew in 100 Accidents (Willen, 1987)

No. of Crew involved	Number of Human Errors											
	0	1	2	3	4	5	6	7	8	9	10	Total
0	4	--	--	--	--	--	--	--	--	--	--	4
1	--	3	18	14	6	4	--	--	--	--	--	45
2	--	--	4	11	16	7	2	1	--	--	--	41
3	--	--	--	1	--	3	2	1	1	--	--	8
4	--	--	--	--	--	--	1	--	--	--	1	2
Total	**4**	**3**	**22**	**26**	**22**	**14**	**5**	**2**	**1**	**0**	**1**	**100**

It is therefore clear, maritime accidents are very complex to comprehend and conclude on specific root cause. Nevertheless, it has been reasonably established that over 80% of maritime accidents were due to human factor. The persuasion of human factors dedicated to comprehend human capacity to deliver and limitations. These in formations on human ability and limitations can be used to improve; design policies and procedures, work environment etc that are compatible to with human abilities. To achieve these objectives, a human cantered approach need to be adopted to increase human efficiency and effectiveness. Given that, humans can both *initiate* and *mitigate* accidents, it is imperative to determine the overall influence of humans in systems reliability in any probabilistic safety assessments. In this way, we can predict the human and mitigate the failure modes. There are various techniques used in Human Reliability Analysis (HRA) and each has its merits and demerits.

Attention to human contributions to accidents started as far back as in 1920, following a review of accident data bases in the chemical industry, which revealed that most of the accidents were due to human factor (Kletz 1999; Wang 2007). Following this revelation, psychologists and behavioural scientists secured data through experiments and simulations that gave insight for analysis and quantification procedures in risk assessments (Gertman 1994). Therefore, the focus on probabilistic study for human reliability is because of its significance in Probabilistic Risk Assessment (PRA) with following purposes:

1) Provide an account and description on manifestation of failure due to human system interaction; the Hazard Identification (HAZID) phase as follows:
    a) Identify the human risks
    b) Classify risks according to severity
    c) Identify frequencies of risks
    d) Divulge the generic causes of risks
2) Develop a model tool for quantification of human factor for input into PSA
3) Find ways to reduce the human contributions to risk (Mitigation)
    a) Through risk –based design
    b) By reviewing management policies

c) Enable international regulatory bodies/insurance to develop rules and guidelines

4) Create documentation for human pattern of failure for identification and safety review

These four main purposes on which human reliability is carried out constitute the components of HRA as demonstrated in Figure 3:5.

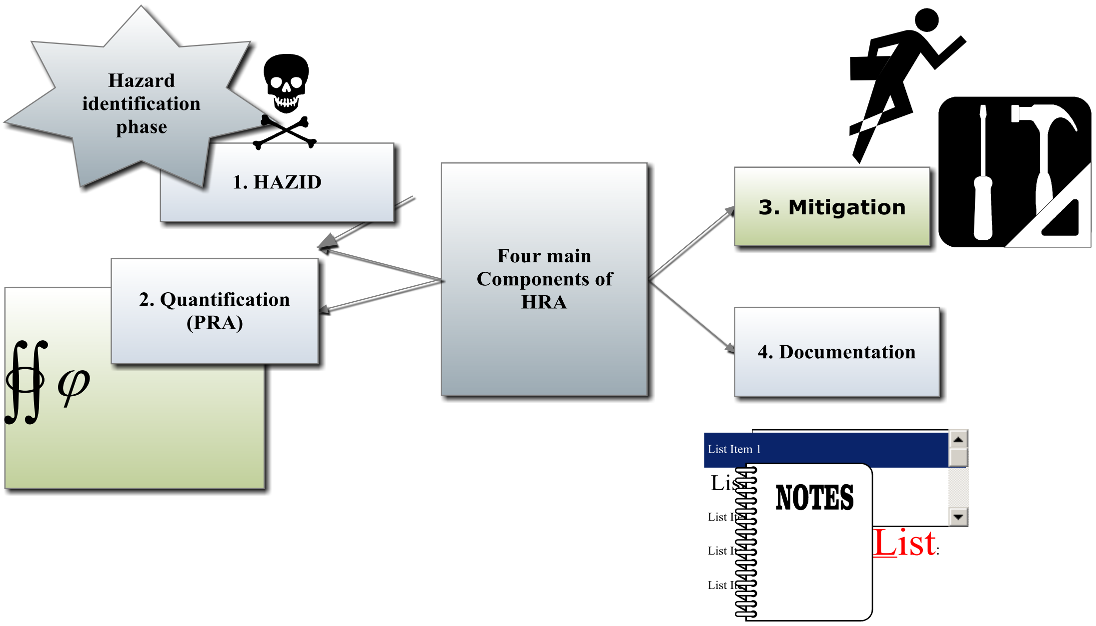


Figure 3:5- Four Main Components of HRA

As human contribution to accidents continues to increase with adverse effects on the environment, infrastructural damage and human losses, the Health and Safety Executive (HES) promulgated that: "*Organisations must recognised that they need to consider human factors as a distinct element which must be recognised , assessed and managed effectively in order to control risks"* (HSE, 2007). Human factor is wide and complex since the pattern of error may be different for different organisations and between different individuals (Kirwan 1992). It is therefore difficult to make a universal or all encompassing HRA model (Ronald, Boring et al 2008).

A number of HRA models for estimating human error probabilities have been constructed and each has its own merits and demerits. The HRA models evolved through various means and each of the models is constructed to represent particular scenarios. Similarly, the model designers' level of experience or view plays an important role in the analysis of human factor (StrÃter and Bubb 1999; Vanderhaegen, 2001; Mosleh and Chang 2004). Presently, there exist over 30 methods that are used for HRA but with far-reaching distinctions in technique and detail. Some of the variations in results obtained from case studies were pointed out by various practitioners (Kirwan, 1994). While none of these models has universal acceptance, most of the HRA models were developed for power plants and chemical industries. There is however a gap in the coverage of HRA technique for mobile systems, in particular maritime and offshore systems (Eleye-Dotubo. 2008). Therefore, in this Chapter the study will focus on:

1) Carrying out an inventory on the scope of coverage in the current HRA techniques
2) Typifying of human element that is specifically dealt with in the HRA and methodology
3) Identifying advantages and disadvantages in each HRA model and specific area of application
4) Finding and isolating existing constrains in HRA modelling

Following this review on the existing practices in HRA, the outline of this research study will then be developed. The research will therefore focus on improving and covering gaps in the existing HRA practices.

3.3 Outline of Current HRA Techniques

Over the years, practitioners have categorised the HRA models into first and second generation models. Though the scopes of detail of the models have improved over time, the categorisation into first and second generation models is without any specific criterion and moreover, it is not based on the time period in which the model was developed.

3.3.1.1 ***First Generation HRA Models***

The first generation models are simple in design and dwelled on human errors of omission or commission and ergonomic issues (Hollnagel 1996). The human system interface which creates unpleasant situations and potentially triggers human error forms the backbone of the quantification in the first generational HRA models. Most of the modelling and analysis technique were reactive and limited in context e.g. non-inclusion of Performance Shaping Factors (PSFs). A list of some first generational HRA models is shown in Table 3-7.

Table 3-7 - First Generation HRA Techniques

Model Type	Meaning	Domain Application
APJ	Absolute Probability Judgement	Nuclear/ Offshore
ASEP	Accident Sequence Evaluation Programme	Nuclear specific
HEART	Human Error Assessment and Reduction	Nuclear/Chemical/Aviation

	Technique	
HRMS	Human Reliability Management System	Nuclear
JHEDI	Justified Human Error Data Information	Nuclear/Chemical
PC	Paired Comparisons	Generic
SLIM	Success likelihood index methodology,	Nuclear/Chemical
THERP	Technique for Human Error Rate Prediction	Nuclear with wider application
TRC	Time Reliability Correlation	Not specified

3.3.1.2 *Second Generation HRA Models*

In the second generation HRA models, humans, hardware and organisational factors were integrated into the modelling sequences (Hollnagel 1998). Furthermore, research by behavioural scientists led to the evolution of what is also called Performance Shaping Factors (PSF). The advancement of PSF enabled contextual understanding of human-system interface. Some of the second generation HRA models are shown in Table:3-8.

Table:3-8 - Second Generation HRA Models

Model Type	Meaning	Application
ATHEANA	A Technique for Human Error Analysis	Nuclear with wider application
CAHR	Connectionism Assessment of Human Reliability	Wider Scope
CESA	Commission Errors Search and Assessment	Nuclear
CODA	Conclusions from occurrences by descriptions of actions	Wider scope
CREAM	Cognitive Reliability	Nuclear / Chemical
INTENT	Not an acronym	Nuclear
MERMOS	Method d'Evaluation de la Realisation des Missions Operateur pour la Surete	Nuclear Industry

	(Assessment method for the performance of safety operation.)	
SPAR-H	Simplified Plant Analysis Risk Human Reliability Assessment	Nuclear, with wider application
SLIM-MAUD	Success Likelihood Index Methodology, Multi-Attribute Utility Decomposition	Wider scope of application
IDAC	Information Decision Action of Crew	Wider application
NARA	Nuclear Action Reliability Assessment	Nuclear

3.3.1.3 *Third Generation HRA*

So far the third generation HRA models have not been mentioned anywhere but, as very few of these models were observed to differ significantly from the previous concepts, they are presumed to be *third generational models*. It is presupposed that any model that has the following virtue should be categorised as a third generation model:

1) The model must define human error and failure modes in context
2) The model must enable mitigation of all identified risks due to human factor
3) The model must be self auditing and support documentation
4) The quantification processes must also support iteration to simulate different scenarios to facilitate mitigation
5) The quantification processes must be comprehensive; qualitative and quantitative and must be easy to interpret
6) The model must be proactive

3.4 Overview of HRA Models

There are quite a number of HRA models that have evolved over time. Some of these models have been put into practice while some are only theoretical. Some of the HRA models which were critically reviewed are as follows:

3.4.1.1 *Absolute Probability Judgement (APJ)*

Absolute Probability Judgement is a first generation HRA model and its concept is straightforward. The APJ technique involves the use of experts for direct generation of human-error probabilities (Kirwan 1994). The premise of APJ quantification was based on the assumption that people can either remember or, are in a better position to estimate the likelihood of human error. The predictions are purely based on people's field experiences and these techniques are still used in forecasting, data generation and validation. The particular technique used in APJ is not fixed; it may occur in various forms, from the single expert assessor to a large group of individuals who may work together or whose estimates may be mathematically aggregated.

The APJ requirements are:

1) The expert must have an in-depth knowledge of the area they are assessing
2) The experts must have some normative expertise
3) The experts meet in a group to share their arguments before a facilitator

Mathematical material for APJ is drawn from Seaver and Stillwell (1983) however the definition of expert has been much debated among practitioners (Kirwan B. (1994)). Bedford T (2006) lists the five generally accepted expert elicitation techniques which could be used in any subjective elicitation. Bedford recommended these methods in order of superiority; Consensus, Nominal Group Technique, Delphi Method, Aggregated Individual and Single Expert/Engineering Judgement.

Pros and Cons of APJ

The APJ has been shown to provide accurate estimates in some fields such as in weather forecasting (Murphy and Winkler 1979). Absolute Probability Judgement is relatively quick and has been applied successfully in weather condition forecasting, nuclear and offshore industries (Blom H.A.P. 2008). In the field of human reliability, APJ plays a key role in providing in-depth analysis of human error manifestation in context. Interactions between experts will enhance the search for error reduction techniques. It is however, susceptible to biases as well as to discord among experts. Similarly, the technique depends upon the selection of requisite experts.

3.4.1.2 *Human Error Assessment and Reduction Technique (HEART)*

HEART was developed as a proactive technique that is also relatively quick to use, like the APJ. The HEART initiative was developed by the author following his practical experience in operations at nuclear power station (Williams 1985). Experimental evidence and literature on human contributions to accident parameters was used to develop the quantitative error probabilities. The model is particularly useful for HRA in clearing design issues. HEART outlines nine generic task types (GTT) and each is allocated a nominal Human Error Probability (HEP).

The HEART technique outlines Error Producing Conditions (EPC) as anything that can increase the probability of error, and allocates to each EPC associated multiplying factors.

Table:3-9 shows some of the GTT and associated nominal probabilities.

Table:3-9 - HEART Generic Categories (Williams, 1986)

Generic Task Category	Proposed Nominal Human Unreliability
[A] Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55 (0.35 – 0.97)
[B] Shift or restore system to a new or original state on a single attempt without supervision or procedure.	0.26 (0.14-0.42)
[C] Complex task requiring high level of comprehension and skill. …… [H] Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage.	0.16 (0.12-0.28) 0.00002 (0.000006-0.0009)

The first function of the HEART is to rank a task in accordance with its generic proposed nominal level of human unreliability. The task is thus classified as a complex or routine task. The next step identifies Error Producing Conditions (EPC) which is evident in the scenario and would have a negative influence on human performance. Table:3-10 shows some of the major EPCs in HEART.

An example of a HEART calculation is shown at Table:3-11 . Assume a GTT classified as Task B (Shift or restore system to a new or original state on a single attempt without supervision or procedure).

Table:3-10 - Major EPCs in HEART

Serial	Error Producing Condition	Max. predicted nominal amount by which unreliability might change, going from a 'good' condition to a 'bad' one
1	Unfamiliarity with a situation which is potentially important but occurs infrequently.	x 17
2	A shortage of time available for error detection and correction	x 11
3	A low signal to noise ratio	x 10
-------	-------	-------
26	No obvious way to keep track or progress during an activity	x 1.4

Table:3-11 - Example of HEART Calculations

EPCs	Total HEART Effect	Assessed Proportion of Affect (APOA)	Assessed Factor
Ambiguity in performance	x 5	0.5	(5-1) x (0.5) -1 = 1

Risk misperception	x4	0.7	(4-1) x (0.7) -1 = 1.1

For Task B (nominal human unreliability) = 0.26.

Therefore, assessed nominal likelihood of failure = 0.26 x 1 x1.1 = 0.286

(Task B = 0.26 (nominal human unreliability).

Pros and Cons of HEART

The concept of HEART is very good as a proactive technique for error prediction and the technique also has a set of practical error-reducing strategies. The model seems to dwell on modelling design issues and is short of details on the cognitive error manifestations (Harris, Yang et al. 2007). The experimental results of multipliers is not convincing since different assessors have different views, and operators differ in capabilities. Similarly, there are no comprehensive practical guidelines, in particular on how to allocate the APOA.

3.4.1.3 *Human Reliability Management System (HRMS)*

Human Reliability Management System (Kirwan 1994) quantification is based on actual data and is fully computerised. The method deals with many aspects of the HRA process and is based on the extrapolation of tasks according to six major PSFs. The system was developed specifically for nuclear plants with a view to improve the HRA such that:

1) It is data based, not expert judgement dependent

2) It is flexible, more detailed and allows rapid screening

3) It has sensitivity analysis capabilities

The HRMS carried out a validation exercise and reviews of some of the HRA techniques through subjective interactions. HRMS was developed to inform the design process and because of the tedious nature of screening process, Justification of Human Error Data Information (JHEDI) technique was also developed alongside to ease the quantification processes. In both cases the quantification is based on industry error data supplemented with expert judgement.

1) There are 6 PSFs – Time, quality of operator interface, quality of procedure, how the task is organised, training, and level of complexity. Task scenarios are described by making requisite reference to the PSFs. Each piece of information on a task is matched with a HEP developed from data. The tasks are categorised and the assessor selects the one that most closely resembles the task being assessed.

2) The HEP associated with the selected task type is multiplied with the PSF value, however the model also allows for interactions between PSFs.

3) HRMS also allows for error reduction analysis by providing a sensitivity analysis to determine the factors that, if improved, will maximise the reduction in risk. This is done automatically in HRMS by comparing with the original assessed profile including an improved PSF

Consequently, HRMS developed a model which covers the six points listed above.

Pros and Cons of HRMS

HRMS is flexible and since it is data based, it can be utilised to inform human system interface advancement for design purposes. It also has a very good error reduction technique in which the risk level is reduced by reducing systems vulnerability through an antecedence data base. However, HRMS quantification processes are tedious and complex. It is also expensive due the demand for high quality experts.

1.1 Time Reliability Correlation (TRC)

TRC is unique in its initiative as a time- based human reliability model (Dougherty 1987). Human reliability is measured as a function of time required to successfully complete an operation in critical situations. A computer simulated time and error factors were developed as shown in

Table:3-12. TRC also measures time to successfully diagnose or decide upon an action (Bedford T and Cooke R 2001). The quantification is based on some psychological postulates on human response in the event of failure with the aid of an event tree. The basic premise of a TRC approach is defined by the author, Dougherty (1988), as follows:

1) It forces the operators of a plant to respond to conditions not of their making or intention

2) It forces the operator to diagnose the situation at hand within the real time of event phenomena, it forces a time schedule on the operator that is uncertain in its detail

3) It forces the operator to succeed in their actions to prevent risk.

4) It enables interpretations of implications on future plant operations and helps managers to decide on future actions accordingly

Human reliability $R(t) = Pr[T \leq t]$.

Table:3-12 -Generated Median Times and Error Factor (Courtesy Dougherty)

Sequence	Influence	Median T	Comment	Error Factor
Loss of Nuclear Instrumentation	Highly Practiced, high awareness, minimum Diagnosis	0.5	No decision	3
Steam Generator tube Leak	Radiation in secondary, well-instrumented, easy to diagnose, high awareness of stopping Rad. Leak	1.3	Procedures clear on how to isolate affected SG	3
Safety injection	Onset of SI obvious, must check other parameters to assure safety system actuation can be terminated	5.3	Onset obvious, must check parameters	3
Small Loss of Coolant Accident	Slow evolving leak, can have many sources, possibility of isolation may take time	9.5	May take time & induce hesitancy	5

The Human Reliability is the elapsed time for successful response to the situation.

$$T = \tau_R \times \tau_U$$

Where;

τ_R $[\tau.k_{c.}k_{psf}\ .\ l_R]$– lognormal random variable with median of m and error factor f_R to account for the uncertainty of the process; τ_U – lognormal random variable with median of l, and error factor f_U to account for uncertainty in the model

Pros and Cons of TRC

TRC can be employed as a modelling tool in HRA for maritime and offshore under emergency situations where time to react is critical to improve personnel knowledge and skills. The judgement for probabilities is plant specific and experts must be drawn from within. However, TRC models are only suitable as a function of time to succeed in an emergency procedure, which limits their application. The TRC approach does not represent the context of situations confronting operators.

3.4.1.4 *Success Likelihood Index Methodology and Multi Attribute Utility Decomposition*

Success Likelihood Index Methodology and Multi Attribute Utility Decomposition (SLIM-MAUD) is a computer based system designed to smooth the progress of SLIM and to reduce expert biases. SLIM was developed in 1983 for the Nuclear Regulatory Commission (NUREG); the quantification is based on expert judgement with a modelling procedure (Embrey, Humphreys et al. 1984; Kirwan 1994). The human proneness to error is judged by manifestation of PSF and experts' judgement of the relative importance and the weighting of each PSF in the task being evaluated.

Having obtained the relative importance of weights and ratings, these are multiplied together for each PSF and the resulting products are then summed to give the Success Likelihood Index (SLI). The SLI is a quantity, which represents the overall belief of the judge(s), regarding the positive or negative effects of the PSFs on the likelihood of success for the task under consideration. It is assumed that, as a result of their knowledge and experience, the judge(s) have a correct idea of the effects of the PSFs on the likelihood of success; the SLI will then be related to the probability of success that would be observed in the long run, in the situation of interest (i.e. the actual determined probability). SLIs are transformed into HEPs using a suggested logarithmic relationship of the form:

$$\text{Log P (success)} = a\,(\text{SLI}) + b$$

$$\text{Log of Success Prob} = a*\text{SLI} + b$$

$$\text{SLI}_i = \Sigma_j\, w_j\, R_{ij}$$

W_j is the weight for the j PSF;

R_{ij} = the rating for the jth PSF for ith task

a = the log of success probability of task a (first anchor value)

b = the log of success probability of task b (second anchor value)

The SLIM procedure goes through the following stages:

1) The selection of the expert panel
2) The definition of situations and subsets
3) The elicitation of PSFs

4) The rating of the tasks on the PSF scale

5) The ideal-point elicitation, and scaling calculations

6) The independence checks

7) The weighting procedures

8) The calculation of the SLIs

9) The conversion of the SLIs into probabilities

10) The uncertainty-bound analysis

11) The sensitivity analysis for error reduction analysis purposes

12) The documentation process

Pros and Cons for SLIM-MAUD

Generally, SLIM –MAUD is tagged as a plausible approach (Kirwan (1994)) because it allows flexibility in the HRA analysis. Many HRA modelling techniques are quite similar to the SLIM approach or have drawn inspiration from it. The SLIM method can be applied to any industry providing the anchor HE probabilities are industry based. Though expert judgement is used to evaluate the PSFs, the allocation of SLIs and dependency is not justifiable.

3.4.1.5 *Methode d'Evalaution de la Realisation de Missions Operateur pourla Surete*

Methode d'Evalaution de la Realisation de Missions Operateur pourla Surete (MERMOS) means "assessment method for the performance of safety operation". MERMOS was developed for the Electricite de France (EdF) (P Le Bot, Desmares et al.

1998). After the initial outline of MERMOS, the authors subsequent papers provided more details (Bieder C, LeBot et al. 1998). MERMOS is hereby classified as a second generation model because of its uniqueness as it only considers human factors in emergency operation and is more comprehensive than TRC methods. The aim of the MERMOS qualitative analysis is to identify as many scenarios as possible leading to the HF mission failure. In MERMOS concept, success or recovery in emergency is a function of 'emergency operating systems' (EOS) which is comprised of:

1) Crew quality
2) Man machine interface (MMI)
3) Operating procedure
4) Workplace
5) Organisation

Mission failure probability is determined based on a given scenario derived from the probability of occurrence of each event in the scenario. The probability failure of a HF mission (P) is analysed as the result of identifiable and non-identifiable scenarios.

P(HF) = P (identifiable scenario failure) + (Pr.action + Pr.diagnostic + Pr.strategy)

P(failure scenario) = P SC/CICAs * P CICAs/SITU * P SITU

CICA is Important Characteristics of Emergency Operations while, Operation

P SC/CICAs designates the probability of appearance of the scenario, given that the associated CICAs are all present.

CICAs/ SITU represent the probability of simultaneous existence of the CICAs, in the presence of other scenarios and this can be accessed via simulation tests.

P SITU is the probability of presence of the properties of the situation participating in the appearance of CICAs.

Pros and Cons for MERMOS

MERMOS is classified as third generation because of its uniqueness in predicting human failure probability in emergency. Unlike other HRA technique that uses task procedures under normal circumstances, MERMOS uses emergency procedures. This technique can help identify critical areas in design to improve redundancy mechanisms. It therefore deals with an important concept of HRA in a more comprehensive way than TRC. MERMOS is an Electricité de France (EdF) proprietary HRA model and is seemingly not readily available. The application is very complex and requires expertise in systems engineering. Similarly, the tool is limited to emergency operations only.

2.1 Cognitive Reliability and Error Analysis Method (CREAM)

CREAM is a distinctive technique and looks into the likelihood that performance as a whole fails or is unsuccessful (Hollnagel 1998). Human performance is described in terms of the degree of control an operator or a team has over the situation. An improved version of CREAM was developed such that a rating of the PSF is used to calculate Mean Failure Rate (MFR) directly without bringing into play human error (Fujita and Hollnagel 2004). The CREAM predictive method assumes four characteristics Control Modes (CM):

1) The Scramble CM

2) The Opportunistic CM

3) The Tactical CM

4) The Strategic CM

CREAM control modes are determined by a set of factors called Common Performance Conditions (CPC) and are not assumed to be independent of one another. The 10 CPCs are: adequacy of organisation, working conditions, adequacy of MMI and operational support, availability of procedure/plans, number of simultaneous goals, available time, circadian rhythm, training and experience, crew collaboration quality and communication efficiency. For a given scenario, the dependence of each CPC is assessed in terms of whether it will improve or reduce likelihood of failure, or whether it is assumed insignificant, as demonstrated in Figure 3:6

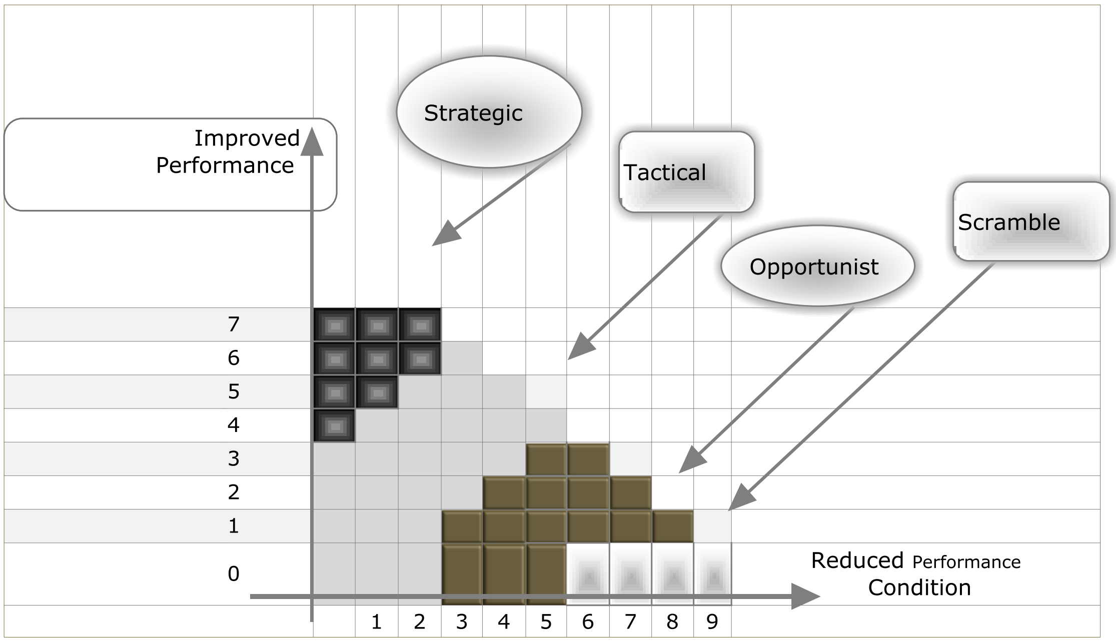


Figure 3:6 - CREAM Modelling Technique

CREAM Cognitive Control Model (COCOM) is also partly subjective as shown below:

$$MFR=MFR_0 \times 10^A \quad \text{for } 0<\theta <\pi/4$$

$$A=R/R_{Max}[1-\theta/(\pi/4)]\log(MFR_{Max}/MFR_0)$$

$$A=R/R_{Max}[1-\theta/(\pi/4)]\log(MFR_{Min}/MFR_0)$$

Where: A is a factor which adjusts MFR_0.

$$R=[\sum_{Improved}+\sum_{Reduced}]^{-1/2}$$

MFR is the mean failure rate; MFR_0, MRF_{Max} and MRF_{Min} are the MFR when CPCs are balanced, maximum and minimum respectively. By this model, a score is derived which expresses the number of CPCs that will improve or reduced the performance of the systems reliability. The Fuzzy Logic modelling approach can thus fit well into the CREAM model (Konstandinidou, Myrto et al. 2006). CREAM's probability axiom is in continuous continuum while the fuzzy logic provides a leeway to the assessor to handle the subjectivity to allocate requisite failure probabilities.

Pros and Cons of CREAM

So far, the Cognitive Reliability and Error Analysis Method (CREAM) seem to be unique and outstanding in harmonising human error causes with context. CREAM seems to be very comprehensive but very complex, and is heavy with assumptions. Because of its improvement of PSFs, it is considered to be a second generation HRA model. The CREAM, classification scheme provides the likelihood that performance as a whole fails or is successful as a function of 10 CPCs (Fujita and Hollnagel 2004). The CPCs were built on a theoretical background and are qualitative. The complexities in CPCs milieu are more pronounced at the quantification stage in allocating descriptors and the expected performance reliability, and are entirely subjective. Allocation of specific CPC in CREAM is entirely the business of the assessor and the descriptors used to define CPCs are too scanty for HRA because of the diverse flexibility that is required. The application of Common Control Mode (COCOM) has not been made clear as it entirely depends upon the quality of the operator. Since in every organisation there are higher quality and lower quality crew, and each of the crew can potentially be a source of failure or a source of success, the CREAM model has not detailed how the various crew members can be distinguished in the quantification. This has made it difficult to use the model in reality, which the author acknowledged (Fujita and Hollnagel 2004).

CREAM is vulnerable to misapplication because of high theoretical demand in cognitive knowledge and is prone to assessor bias. The HEP values used, which were obtained from HRA, do not seem to be compatible with CREAM human failure concept for two reasons: Firstly because CREAM was developed to cover gaps in the existing HRA model, for its lack in context and that the HEP values used by existing models were derived either from simulators or taken from data that was composed on errors of EOM, ECO, slips etc. The second reason is that the usage of failure rates does not fit into HRA; this notion is flawed. Humans are not like technical hardware that can exhibit fixed failure rates, humans are dynamic and differ from one another therefore human performance is best judge by influencing factors (Torell and Avelar 2004).

3.4.1.6 *Nuclear Action Reliability Assessment (NARA)*

NARA was developed by a team of HRA experts using HEART methodology with updated data. NARA was specifically developed for a specific nuclear plant application (Kirwan et al 2005).

The quantification for human error utilises the HEART model:

$$HEP= GTTx\{[EPC1-1) * APOA1 + 1] * [(EPC2 - 1) * APOA2 + 1] * \ldots [(EPCn-1) * APOn+1]\}$$

The Generic Task Types (GTT), Error Producing Conditions (EPC) and Assessed Proportion of Affect (APOA) were updated to match up with current designs, and lessons learned over the years. The upgrade or modifications on HEART as compared to NARA are:

1) In the assessment of crew reliability, time to factor was considered which give crew greater latitude to recover
2) Elaborated guidance on the usage of APOA in the quantification was developed to guard against biases.

Pros and Cons of NARA

NARA is considered a new version of HEART and it is assumed that the updated data and experience gained over the years has been used as an advantage in the upgrade. Elaborated guidance on the usage of APOA will go a long way in reducing assessor biases. The model could not account for dependency such as manifestation of stress in the long run. Details are not readily available

3.4.1.7 *Connectionism Assessment of Human Reliability (CAHR)*

CAHR has wide application ranging from aviation, occupational health and safety, ergonomics and nuclear safety, and is presumed to be a second generational HRA tool (Strater 1997). CAHR was built on experience using event knowledge –based data. The data base contains sequences of events which are extendable by description of supplementary events as shown in Figure 3:7 and CAHR focuses on:

1) Analysis of a system or platform
2) Man machine interface in relation to the operational environment

3) Analysis is open with a fixed querying structure

4) Descriptive information in the analysis on observable events and accompanied causes such as ergonomics and equipment

There are three key elements to the tool (Strater, 2000):

1) A framework for structured data collection (both retrospective and prospective information)

2) A method for qualitative analysis

3) A method for HRA (quantitative analysis and qualitative)

The method is underpinned by a “connectionism algorithm” which is a term coined by modelling human cognition on the basis of artificial intelligence models. It refers to the idea that human performance is affected by the interrelation of multiple conditions and factors rather than singular ones that may be treated in isolation (Everdjj and Blom, 2008).

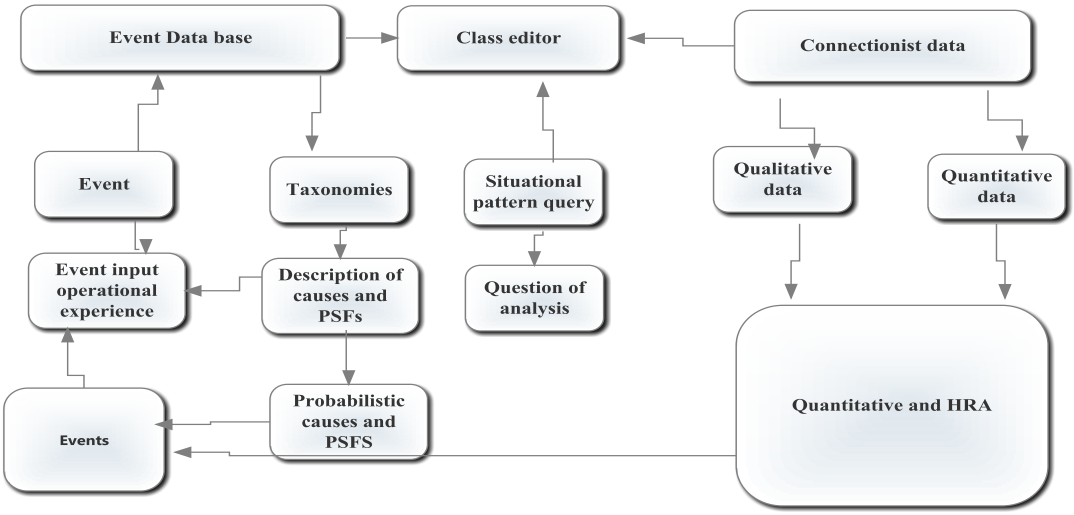


Figure 3:7 - Structural outline of CAHR Modelling Technique

Pros and Cons of CAHR

CAHR has an advanced view assessment on human-system interaction. CAHR has an open analysis technique with fixed querying structure, which makes it applicable to other industries. The technique need for high level expert makes it expensive to use.

3.4.1.8 *Human Cognitive Reliability (HCR)*

Human Cognitive reliability (HCR) was developed mainly for the Nuclear Power Plant (NPP) (Hannaman, Spurgin et al. 1984). The method is based on task analysis and therefore is built on the concept of task diagnosis, error identification and error recovery as a function of time. HCR utilises Rasmussen's concept of rule-based, skills-based, and knowledge-based decision making to determine the likelihood of failing a given task, as well as considering the PSFs of operator experience, stress and interface quality. The database underpinning the HCR methodology has its origin in NPP simulations. This model also gave birth to Systematic Human Action Reliability Procedure (SHARP), by the same author (Kirwan 1994). The premises of HCR Model:

$$T1/2 = T1/2 \text{ nominal} * (1+K1)(1+K2)(1+K3)$$

T1/2 is the nominal time usually determined by expert judgement or simulation experiment. K1, K2 and K3 are the PSF coefficients for experience, stress and operator quality.

Pros and Cons of HCR

The technique is fairly quick but the PSFs selected are seemingly inadequate and the model is only based on time to execute tasks in emergency situations. The mathematical justifications of the model require validation. A pilot project was undertaken using Human Model Simulation (HMS) with a view to rectify some of the inadequacies of HCR in model details (Wei and Hidekazu 1997). The pilot project gave birth to the Human Model on the premise of HCR which also concluded with a need for upgrade (validation).

3.4.1.9 *Human Element Assessment Tool (HEAT)*

HEAT was specifically designed for the maritime industry, to gauge human performance in comparison with the International Safety Management code (MCA 2005). HEAT is based on questionnaires, which are used as '*aides-memoires*' to interrogate ships available safety apparatus. The inspiration for HEAT came from the Safety Culture Maturity Model (SCMM) which is an offshoot of the Capability Maturity Model (CMM). The relativity of SCMM and the HEAT concept is shown in Figure 3:8.

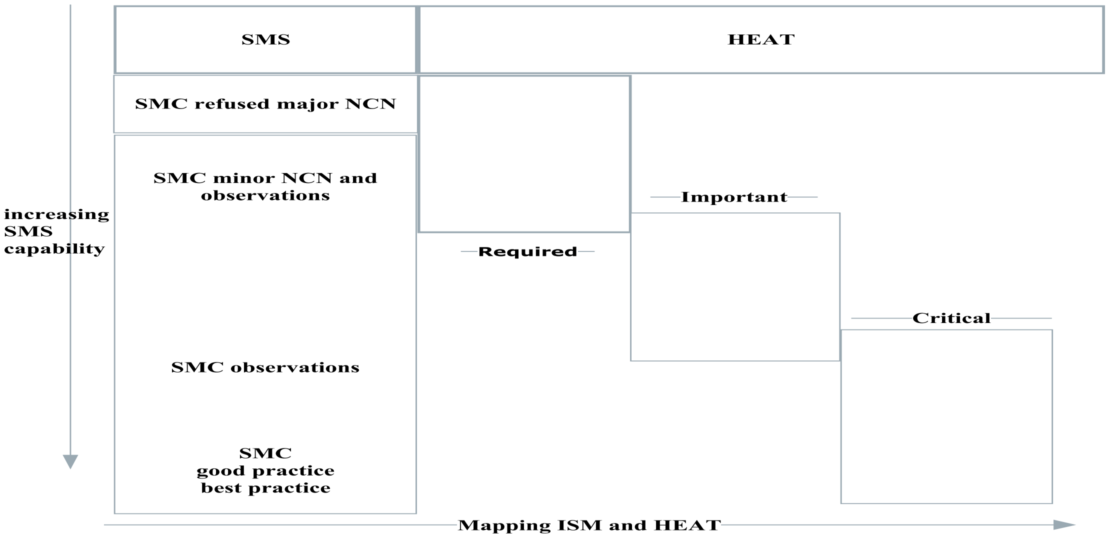


Figure 3:8 - Relativity of SCMM and the HEAT concept

The SCMM is an offshoot of CMM which was indirectly adapted by the Health and Safety Executive (HSE) for offshore applications (HSE 2001). The CMM was primarily developed by the Software Engineering Institute (SEI) to weigh up and safeguard software progression in design and maintenance (Paulk 1993). The CMM itself is a questionnaire- based model and provides an apparatus for self assessment to gauge progression in quality and safety culture. Conceptually, the organisational current level of safety (referred to as maturity) is evaluated using structured questionnaires, and issues of improvement are subsequently followed. The Capability Maturity Model was build upon five levels of maturity in safety as depicted in

Figure 3:9. At each maturity level, requirements to advance to the next level of safety are identified in succession. The model was deemed appropriate for application as a tool to improve safety in the offshore industry and therefore adapted and modified by HSE as the Safety Culture Maturity Model (SCMM). Specifically the SCMM was to serve as an aid to the offshore oil and gas industries to develop the safety maturity culture and where necessary, sort out "grey areas" to improve the safety culture

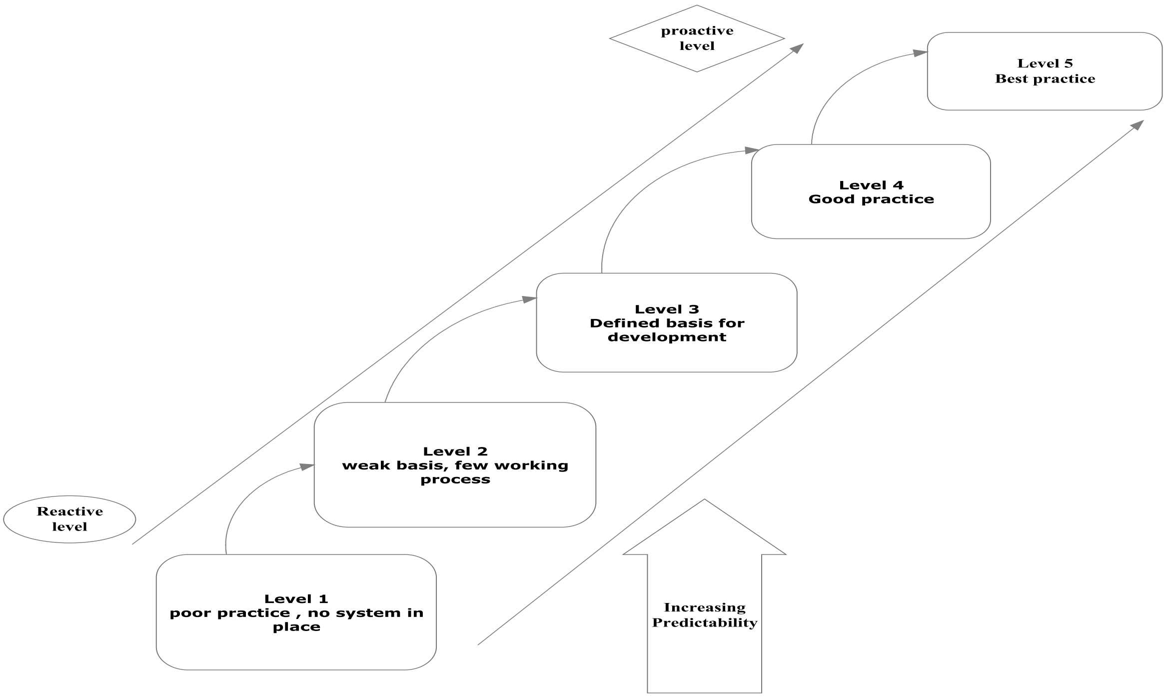


Figure 3:9 Schematic Representation of HEAT Concept

According to the SCMM the safety maturity level of an organisation can be gauged by the following ten aspects at each of the five levels; Management commitment and visibility, Communication, Productivity versus safety, Learning organisation, Safety resources, Participation, Shared perception about safety, Trust, Industrial relations and job satisfaction and Training. The maritime Coast guard Agency (MCA) categorised HEAT into two parts: HEAT-C and HEAT-S. HEAT C was developed to assess the company safety culture whilst, HEAT-S is mainly for the assessment of human (crew) vulnerability to error. The capability levels for HEAT-S are shown in Table 3-13 with the ten typical explanatory details of expected survey outcomes.

Table 3-13 - HEAT-S Capability Levels

Level	Band	Meaning
Best practice	A	Safety practice is more than industry standard. Human factor

		is adequately addressed in operations
	B	High level of safety in human-system interface is practice, in other words best SMS is in practiced
Good practice	C	Best practices of SMS and its advancement
	D	Good human factor practices and in compliance with SMS
Defined basis for development	E	SMS practice satisfactory however, weaknesses observed in critical indicators
	F	Considerable gap in management of critical indicators with minor underperformance in some important indicators
Weak basis, a few working process	G	Considerable gap in management of critical indicators and in many important indicators
	H	Some major shortfalls in critical and important indicators
Poor practice no system in place	I	Several shortfalls in both critical and important indicators. These shortfalls are acknowledged by management, corrective action being considered
	J	Unacceptable levels of underperformances in all indicators. This also indicates that the on-board SMS system is breeched

Pros and Cons of HEAT

HEAT is a subjective tool and is primarily developed for maritime application. In a wider perspective, unlike the ISM code, the HEAT '*aide-memoire'* which was designed to interrogate safety culture can potentially represent the ISM code in safety assessment. However, the HEAT "*aide-memoire*" is very long and since it is purely subjective, it is difficult to eliminate bias. The disparity between HEAT-S and HEAT-C is ambiguous;

similarly, the indices to measure the human element in HEAT-S lacks requisite human assessment input indicators.

3.4.1.10 ***Tripod-Delta (1993)***

Tripod-Delta was created for Shell Petroleum in 1993 by a research team from the Universities of Leiden and Manchester (Hudson, Reason et al. 1994). This technique is proactive with the following elements:

1) Methodology for identifying weaknesses in safety management systems
2) Integrated way of thinking about the process that disrupts safe operations
3) Set of instruments in the form of 'General Failure Types' (GFTs) for measuring disruptive process

The designers of Tripod-Delta reviewed accident records of a number of companies and developed 11 GFTs. The GFTs are the generic causes of Lost-Time Injury (LTIs) that were identified to reflect workplace and organisational factors. An objective picture of the strengths and weaknesses of the organisation is built within the framework of eleven Basic Risk Factors. The GFTs are; Hardware, Design, Procedure, Maintenance management, Error enforcing conditions, Housekeeping, Incompatible goals, Communications, Organisation , Training and Defences

The assessment for any type of operation is gauged from a standardised checklist based upon specific indicators of the presence and degree of each GFT. The indicators are subjective, obtained from task specialists. The sample questions used in the Tripod Delta methodology are:

1) In the area you work, is it always clear "who is responsible for what"?

2) During the past six weeks, have you performed a task of which the execution took more time due to full compliance with the procedures than justifiable for the extent of the job?

3) During the past three weeks, have you had to spend too much time on relatively minor issues?

4) During the past three months, have you obtained information via “informal channels” which you should have received the official way?

Tripod software is used to develop the GFTs scores as indicated in Figure 3:10. Each GFT is measured against a standardised checklist and the programme is run to generate the failure state profile in the form a bar chart. The bar chart shows the relative cause of concern for each of the GFTs. From the chart, incompatible goals, training and design were identified with least scores and hence, in need of improvement.

Pros and cons of Tripod Delta

Tripod Delta is built from a practical view and is indeed a good tool for proactive assessment of safety. Though the GFTs were composed to provide clues to unsafe conditions, it is however not a good representative of practical conditions in operations. The design of GFTs does not consider bounded rationalities and extraneous acts in operations.

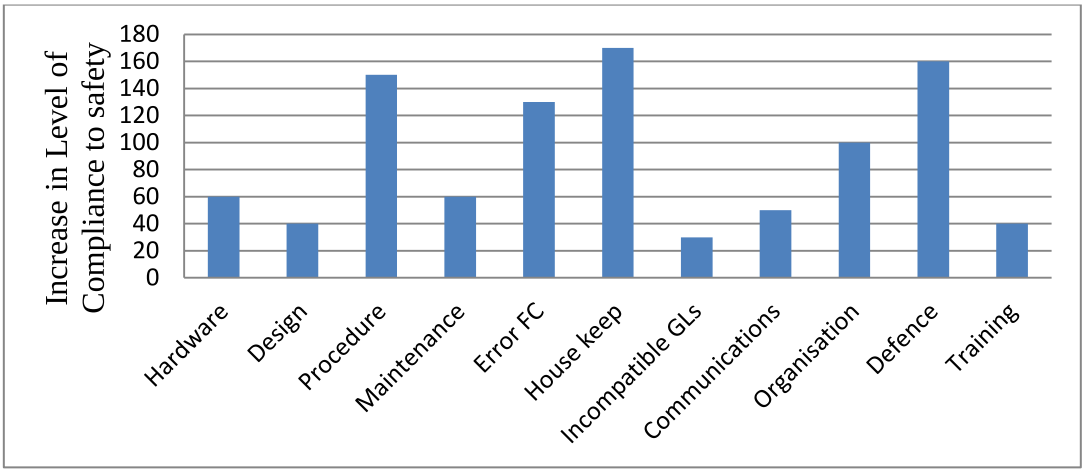


Figure 3:10 – Sample Tripod Delta State Profile

3.4.1.11 ***Standardised Plant Analysis Risk (SPAR-H)***

SPAR-H was developed in 2005 by a group of prominent human reliability practitioners for nuclear power plant applications (Gertman, Blackman et al. 2004). The need for SPAR-H evolved in 1990 whose aim was to improve existing HRA model so as to be integrated with the Accident Sequence Precursor Program. SPAR-H 2005 is the third revised version whose requirements were; Improved modelling procedure, Ease of use and Traceability. The outlines of the SPAR-H frame are shown in Figure 3:11:

1. Decomposes Probaility of human failure into 2:
(1) . Diagonosis failure
(2).Action failure

2. Accounts for PSF and associated depencies

3. Employed β-distribution for uncertainty

4. Designed worksheet to facilitate consistency

5. Allows flexibility

Figure 3:11 - SPAR-H Modelling Framework

The SPAR-H framework relies on the use of Performance Shaping Factors and categorises human error probability into diagnosis failure and action failure. Modelling in SPAR-H can also be carried out using event or fault trees, and depicting how component failure propagates can be done graphically using fault tree.

Pros and Cons of SPAR-H

The SPAR-H is excellent in flexibility since it requires the analyst to consider plant-specific PSF dependencies. The use of base-rate probabilities which were comparable to HEART, THERP or CREAM is not tenable. The base rates computed by other practitioners that were assumed comparable to SPAR-H were developed in the 80's and 90's for the same plant, and as a consequence, it is assumed that development in technology must have mitigated those errors. The multiplier for stressors is also higher than that produced by other practitioners, which symbolises stagnation or decline in advancement in the NPP industry.

3.5 General Characteristics of HRA

The key target in human reliability analysis is to ascertain the probability that operators perform incorrect actions which may lead to undesirable events. However, the quantification, definition and representation of human failure modes have been a major problem due to the complexity of human nature. The problem is however not overwhelming; operational experience and cognitive science are key to solving the human factor incongruity. Table 3-14 provides an insight into how complex the human factor can be visualised and represented in Probabilistic Safety Assessment (PSA).

Table 3-14 - Trends in Human Factor Analyses

Definition of Problem	Human Reliability Focus	HRA Modus Operandi
Human response to task	Capability to execute task correctly and safely without any latent failure mode	Task Analysis
Error identification	Proactive systems thinking to anticipate, clear risk and device alternative solution	Error analysis
Emergency situation	Mitigation and Appropriate Recovery	Crew quality analysis and system redundancy recovery path or resiliency to failure
Error reduction technique	Learning from previous events and setting improvement	Error reduction and representation

The problem of defining human failure dominated the characteristics of HRA models and hence the practitioners developed models accordingly to reflect his/her findings.

3.6 Pattern of Human Error (HE) and HRA Models

Although there is no universal criteria that defines content and context of human error, however, attempts have been made to define what is meant by error and quite a number of variations in the taxonomy and classification of human error/factor have been advanced. Practitioners have used different acronyms and interpretation such as:

1) Crawley, defined human error as :"*A discipline concerned with designing machines, operations, and work environments so that they match human capabilities, limitations, and needs*" (Crawley, Preston et al. 1990)

2) Health and Safety Executive (HSE) defined human factors as '*Environmental, organizational, and job factors, and human and individual characteristics which influence behaviour at work in a way which can affect health and safety'* (HSG48, HSE 1999).

3) Bea, defined human error as '*Departure from acceptable or desirable practice on the part of an individual that can result in unacceptable or undesirable results'* (Bea H, 196).

4) Reason, defined human error as '*The failure of planned actions to achieve their desired ends-without the intervention of some unforeseeable event'* .(Reason J 1990)

Thus, human error is viewed differently by different human factor professionals according to their domain of specialisation as shown in Figure 3:12. A training specialist will attribute human failure to 'training lapses' and therefore tend to demand further training of crew. A manpower analyst will blame '*application of tasks to operator*' and will demand for improved manning levels. Human factor engineer will also attribute the same to '*human factor design problem*' which means either reviewing ergonomics issues or a review of the design to enhance flexibility by introducing redundancy systems and simplification of the current system.

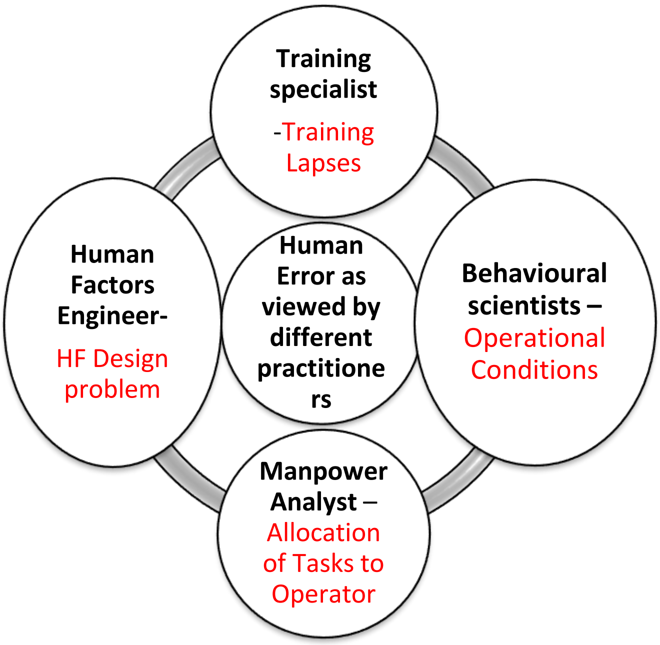


Figure 3:12 - Human Error as Viewed by Different Practitioners

3.7 General Classification of Human Error (HE)

There are also, quite a number of variations in the taxonomy and classification of human error or human factor. Various practitioners used different acrimony and interpretation of human factor/error as shown in Table 3-15.

Table 3-15 - Classification of HE

Type of Human Element	Description	Characteristic Error Type
Attention	Loss of concentration	cognition in the form of: slips, fumbles, EOC,EOO
Memory	Mental judgemental failure	Cognitive
Interruption	Hindrances, alarms, phone calls, announcements, paper work etc.	cognitive, volitional

Operational	Bounded rationality, assumptions, etc	cognitive, volitional
Identification	Mistakes	cognitive, volitional

Therefore, the HRA models which were discussed above were based on the following decisive factors:

1) The domain area of interest or observed problems in the system e.g. Chemical plant
2) The knowledge and experience of the model designer e.g. Psychologist or Engineer
3) The level or degree of accuracy required in the organisation being studied for example, a precision industry such as nuclear plant, aviation etc.
4) The availability of historical data on human contributions to accidents
5) The methods used to obtain human failure data (where historic data is not available) e.g. simulation, experiment etc
6) The resource usage and availability

3.7.1.1 ***Pre-Accident Human Error Analysis***

These are tasks which '*if performed incorrectly could result in the unavailability of necessary systems or components* …' (Swain 1987). Pre-accident analysis is none other than screening of procedures; the analyst's interest is in proneness to error through:

1. Identification of sequential gaps in operations, e.g. deficiency in operational procedures, calibration, tests and maintenance related pre checks.
2. Measurements of task complexity e.g. excessive mental tasks, conflicting priorities etc.
3. Identification of ergonomically sensitive areas e.g. poor layout, inadequate physical restrictions etc.
4. Examination of manning levels such as, extended vigilance

The scope of all the factors covered is only a function of the model designers' knowledge and experience. It is possible to generate data for pre-accident human errors but it may not represent all conditions, and not all humans can be susceptible to the same error. However, the accuracy of pre-accident models lies in historic data. Task description techniques include charting, such as process charts, functional flow diagram and operational sequence diagrams, all of which can be represented in an event tree modelling technique. Some of the models that could be used in pre-accident HRA are: ATHEANA, SLIM, HEART, APJ and CREAM. The Pre-Accident Screening model does not have the apparatus to identify latent errors which may have been caused due to extraneous influences, or acts of rationality.

3.7.1.2 ***Post-Accident Human Error Analysis***

These are tasks '*which are intended to assist the plant to cope successfully with an abnormal event*' Swain (1987). Task description techniques include timelines, input-output diagrams, information flow charts, and decomposition methods etc, all with a view to identifying causal factors and recovery paths. The difference between post-accident analysis and diagnosis is indeed very slim and entirely depends on the context to which it is applied. The Post-accident error analysis model is a tool that could reveal immediate and root causes of abnormal conditions, or failures and the technique can be data fixated. Some of the models that can be applicable in post-accident HRA modelling are: HRMS, JHED, HEART, ASEP and CREAM. Like diagnosis/recovery analysis, post-accident models are retrospective and are used to predict how crew can switch to emergency operating modes or develop other means that could counter failure (resiliency).

3.7.1.3 ***Recovery/Diagnostic Pathway Analysis***

Swain (1987) defined recovery path as '*figuring out what to do when an abnormal event has been recognised*'. Predictions for human ability to recover are often complex and hypothetical; a function of systems robustness, and flexibility or reversibility. Recovery can be facilitated by logistics, crew quality, supervision, communication etc. That notwithstanding, recovery and diagnostic pathway analysis are not far removed from each other. Very few HRA models have wherewithal for error recovery except for THERP and MERMOS. Other models of unique characteristics are TRC and HCR, which are seemingly for diagnostic or recovery purposes and each predicts the probability of human action as a function of response time. TRC and HCR models are not comprehensive enough as HRA tools because only a single time-dependent event is considered, rather than overall performance. The fundamental difference between human failure and hardware failure is that; not all humans can make the same error and can recover contrary to a component part. Similarly, these time-based HRA models have not been able to represent the PSF in the quantification process; only the time taken to succeed or prevent systems collapse in the event of failure is measured.

3.8 Pros and Cons of Existing HRA Models

'Prediction of human malfunction in a task considered in isolation is not very meaningful. The basis for any human error prediction in the present context will be the result of a functional analysis of the technical system or the task environment including a failure analysis' (Rasmussen 1982)

The following main issues were observed in the current HRA practices:

1) Taxonomy of human failure mode and its causes
2) Taxonomy and representation of PSF
3) Availability and accuracy of calibration or representative data
4) Domain of HRA model application and modelling flexibility
5) Subjectivity of HRA models

3.1 Taxonomy of Human Failure Modes and their Causes

As there are different definitions of human error, so there are also different interpretations of human failure modes and their causes. Human Failure modes are the human behaviours that could manifest into error and lead to systemic failures. Reason (1997) classified human error types into three categories: Skills, Rules and Knowledge-based (SRK). The human failure modes may be in the form of mistakes, fumbles, slips, lapse and violations (routine, optimising or necessary). In most cases, minor things go wrong or little mistakes are made through adjustments. Therefore, even while accidents are all too often blamed on human in-attentiveness or disorderliness, more often than not they are indicative of deeper and more complex activities. Thus, failure is not only a a result of human-incompatibility to prevailing circumstances' in operations.

The first generational HRA models concentrated on reactive modelling using data on human error and as a consequence, human contribution to failure were limited to Errors of Commissions and Omissions (ECO,EOO), except for the Absolute Probability Judgement (APJ) model that had a broader perspective. Fundamentally, the ECO and EOO do not provide the requisite information needed to gauge human error in HRA. Both ECO and EOO indicate classes of incorrect actions with no distinction between manifestations and causes. Similarly, quite a handful of errors exist which cannot be classified under ECO or EOO (Hollnagel E 2000). The THERP error probabilities are the best fit for design application because of their sequencing disposition. THERP error probabilities were derived from the following types of errors with refinement:

1) Errors of Omission (EOO) - The EOO is basically task-based, and distinctively depends upon the system or industry

2) Errors of Commission (EOC) – The EOC comprise of: selection, sequencing, timing and quantitative errors all of which were developed from the THERP data base

Despite the fact that safety violations in operations are common in most industries, and have been reported in the form of routine, necessary and optimising, none of the HRA models attempt to represent these failure modes in their taxonomies. Human factors analysts and practitioners have reported extraneous acts and bounded rationalities in operations, and yet human failures are centred on basic human error (Leveson 2004). According to Hollanagel, '*The notion error is vague*', as it only indicates the cause, event or an outcome of an incorrect action (Hollnagel E 2000). Unfortunately, given the plethora of logically different modes of human failures, axiomatisation of failure is still concentrated around the human error mode. Others have maintained that most accident enquiries have revealed that '*bad events are more often the result of error-prone situations and error-prone activities, than they are of error-prone people*' (Reason J 1997). These error-prone situations and activities are *contexts of the failure modes*, not just the action that led to failure (Fujita Y. 2004) .

The evolution of 'Efficiency Thoroughness Trade-Offs' (ETTO), points towards more realistic and practically oriented human factors assessment. This will enable accurate representations of human error in Man Machine Interface (MMI). The in ability to explore, classify and represent human failure modes in HRA has led to the accuracy and credibility of the quantification being questioned. And there has been outcry pushing for more robust searches, as error is just the starting point for investigation into how failure occurs (Wiegmann 2001; Leveson 2004; Woods 2007; Hollnagel 2009). Human-system endeavour is beyond error and the fact that the human is a logical actor gives him/her latitude to utilise knowledge around ideals, as dictated by operational exigencies (Fujita and Hollnagel 2004; Wiley Jee and Benjamin 2007). Situational changes can make humans unreliable or unpredictable as he/she struggles to maintain operability of the system without mitigating the consequences. Systemic-interferences may lead to immediate accident or remain in the system as *pathogens* until this manifests as latent error and gives way to accidents (Reason. 1990). Operating a technical system involves innumerable interrelated subsystems including the operator, and we need to think in terms of these interrelations. We can therefore look into the manifestation of human contribution to failure in Man Machine Interface (MMI). Therefore, taxonomy of error based on Skills-, Rules- and Knowledge -based (SRK) classification is shown in Figure 3:13 (Reason, 1997). However, this classification is not enough in HRA as Reason in his treatise discussed volitional acts as prevalent in accidents.

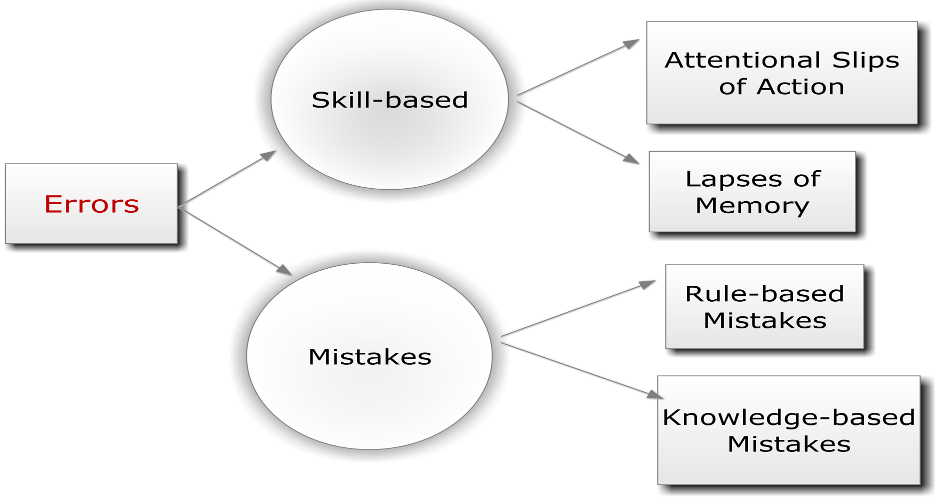


Figure 3:13 - Classification of error types

The non inclusion or inability to incorporate volitional acts in the form of bounded rationalities has made most of the HRA models unsuitable/incomplete in quantifying the human element. Though retrospective analysis has its advantage, it is also limited due to systems dynamism.

'*Systems and organisations continually experience changes as adaptations are made in response to local pressure and short-term productivity and cost goals*' (Leveson, 2011). In other words humans would always like to change the environment to suit his condition or change to adapt to the environment.

3.9 Taxonomy and Representation of PSF

The taxonomy of the Performance Shaping Factors (PSF) in HRA has been dealt with extensively. The scope and application of the PSF entirely depends on the HRA model developer or analyst and the intended sector to which it is applicable, and as a result, different nomenclatures for PSFs have been used, such as:

1) Performing Shaping Factors (PSF)

2) Performance Influencing Factors (PIF)

3) Performance Affecting Factors (PAF)

4) Error Producing Conditions or Factors (EPC/EPF)

5) Common Performance Conditions (CPC)

6) Pre-Condition for Unsafe Acts (PCUA)

Due to varying way in which the PSFs are developed, and their intended usage, a number of disparities arise such as:

1) HRA is both quantitative and quantitative, so the PSF must also be represented in quantitative terms (probabilities). This has led to variation in the HEP values generated through the different methodologies which also led to disparity in overall result. Therefore, any attempt to make comparison between different HRA results is pointless

2) The numbers of PSFs are limited for each methodology, as a result of which some models may have fewer PSFs than other models. Consequently, limiting the number of PSFs can lead to inaccuracy in quantification and in error reduction measures

3) The definition of terms and context of each PSF differs by method which also constitutes variability problem between different assessors and leads to differing results

4) The duplicity and dependency in selected PSFs differs in various ways. While some models have attempted to account for dependency within PSFs in a quasi manner such as in THERP, others have not even been able to devise the means to filter duplications of PSFs that are often repeated in the quantification process

5) Variability in the representation of PSFs due to different modelling techniques is therefore imperative, as highlighted above. In addition to that, the industry or organisation that was used as the subject for the HRA study is the source of greater viability in PSFs representation. For instance, the Aviation and Nuclear industries require greater operational precision than the maritime industry which makes the scope and context of PSFs differ considerably.

Kim et al (2003) carried out extensive work on the taxonomies of Performance Influencing Factors (PIF) for HRA, and exploited the different categorisation in use, as shown in Figure 3:14

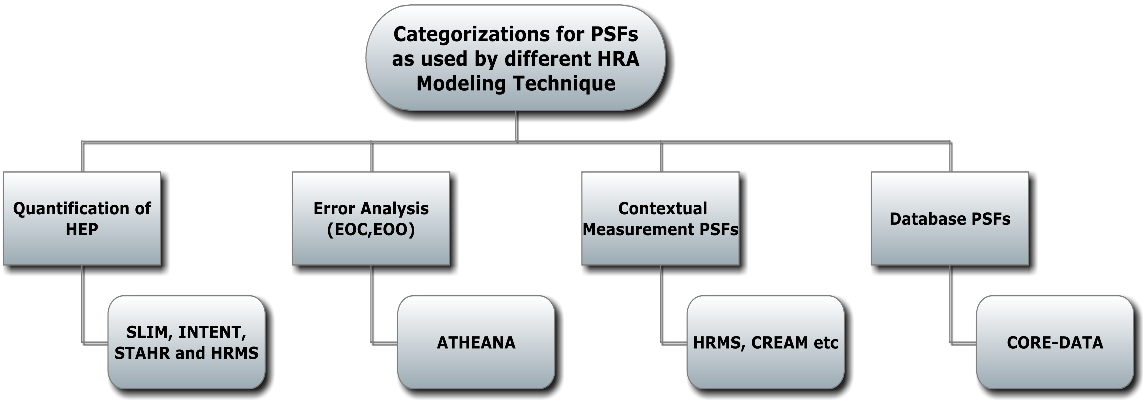


Figure 3:14- Categorisation of PSFs

Most of the HRA models that use PSFs fall under these categorisations. In the quantification of HEP, PSFs are used to identify human error and estimate the probabilities by mapping onto an HEP distribution e.g. in INTENT (Gerttman and

Blackman 2004). Overall, in HRA it is not the probability values that matter but rather what these values represent in the context. The PSFs are used to model human behaviour as the causes or contributors to abnormal behaviour or deviation from safe practices. In view of the present works in HRA, a review of the PSFs was carried out to identify those relevant to maritime applications.

3.10 Calibration/Representative Data

In general, since the reliability of the HE data bank is questionable so also the reliability of any data driven calibration. Issues regarding data for HRA have been dealt with in various studies with much concern. Some of the key questions about the originality and representativeness of data are (NEA 1998):

1) Task - What was the task given to the person?
2) Person - Who was the person involved in the event?
3) Action - What has the person done?
4) Feedback - What were the information sources to check what has to be done and what has been done?
5) System - What part of the system has been manipulated?
6) Environment - Where has the event happened?
7) Transaction - What had the person to do to inform others about his work?
8) Organisation - What are the contributing organisational factors?
9) Time and Duration - When did the event happen and how long did it last?

Answers to these questions are vital in developing HRA models so as to capture the error mode in context. Human error data bases do not provide the requisite information and unlike component failures, human failure rates cannot be constant since individuals differ. Data on human contributions to accident proved difficult to use because industries deny information on the root causes, and where such data exists, it may be disputed by those involved (Gordon R, Flin et al. 2005). Although different persons may cause different failures and is not likely to commit the same errors repeatedly, the data may still be useful for pattern identification of human disorderliness. Therefore, since the reliability of human error data is questionable, any attempt to use such data to validate HRA models is also questionable. Data based HRA models are retrospective in design and therefore limited because systems and human behaviour are dynamic.

4.1 Flexibility of HRA Models and Domain of Application

Although research in the field of HRA has proliferated in recent years, it has stretched across various industries. Therefore, most of the HRA models are not readily flexible because application is restricted to the industry in which the model was referred. Similarly, like the THERP technique, the error probabilities were tied down to the original data even though, technology has advanced and error modes have changed.

3.11 Subjectivity of HRA Models

Human reliability analysis is twofold; qualitative and quantitative. The qualitative part is concerned with identification of human error-prone situations. This subjective stage is often achieved through discussion, task analysis and interactions etc. This method, used to generate data, has been widely criticised by frequentist and other practioners due to lack of coherence, credibility of experts (in terms of experience and biasness) and in some cases requires calibration data (Swain 1990). Some of the HRA models such as APJ, SLIM, CREAM etc have judiciously applied qualitative means in modelling, whilst other models like THERP, TRC and HCR have relied heavily on data. That notwithstanding, the subjectivity in HRA is imperative because humans differ in capacity, knowledge and productivity, proneness to error and modes of failure. Therefore, capitalising only on data will produce misleading results. Most of the models have qualitative and quantitative parts, the only issue is whether or not the right experts are used and correct elicitation screening procedure is carried out.

3.12 - Other Issues Observed in This Study

So far, the Cognitive Reliability and Error Analysis Method (CREAM) seem to be unique and outstanding in harmonising human error causes with context. The CREAM classification scheme clearly provides the likelihood that performance as a whole fails, or is successful, as a function of 10 Common Performance Conditions (Fujita and Hollnagel 2004). However, some issues have been observed:

1. The CPCs are not well defined which makes the dependency among the CPCs very complex. The complexities in CPCs milieu are more pronounced at the quantification stage in allocating descriptors and the expected performance reliability, and are entirely subjective. Allocation of specific CPCs in CREAM is entirely the business of the assessor. Moreover, the descriptors used to define CPCs are too scanty for HRA because of the diverse flexibility that is required.
2. The application of COCOM has not been made clear; it entirely depends upon the quality of operator. Since in every organisation there are higher quality and lower quality crew, and each of the crew can potentially be a source of failure or a

source of success, the CREAM model has not detailed how the various crew members can be distinguished in the quantification. This has made it difficult to put into reality, which the author acknowledged.

3. Though CREAM tries to provide explicit systemic human interaction reliability analysis, as the qualification is lacking in practical realities, it is entirely psychological. CREAM is vulnerable to misapplication because of high theoretical demand in cognitive knowledge and is prone to assessor bias. In Fujita (2004), the analysis made on train crashes was based on assessors' interpretation of the situation and despite the fact that the train driver died in the crash, it was observed that :

a) The assessor inadvertently assumed that Crew Collaboration (CCQ) was not important thus restricting CCQ to act as a function of co-workers onboard; however CCQ could be extended to include shore crew via communication links.

b) Similarly, under adequacy of organisation and adequacy of training the assessor dwelled on auto stopping system being breached by drivers even though he is not sure whether the driver violated the alarm procedure or not.

c) Another overlap was observed in the analysis on working condition; manoeuvring in a blind spot (curve) is a function of training and operational support but, as mentioned above, the analysis was tied down by the assessors' view since no criteria for measurement was available.

4. As highlighted previously, the HEP values used were obtained from HRA literature which does not seem to be compatible with CREAM human failure

concept for two reasons: First, CREAM was developed to cover gaps in the existing HRA models for its lack in context unfortunately; the same HEP values were used in CREAM. The second reason is that the usage of failure rate does not fit into HRA, this notion is flawed. Humans are not like technical hardware that can exhibit fixed failure rates, humans are dynamic and differ from one another and generically, human performance is best judged by influencing factors (Torell and Avelar 2004).

5. That notwithstanding, the Fuzzy Logic modelling approach in (Konstandinidou, et al. 2006) fits well into the CREAM model. CREAM's probability axiom is in continuous continuum and the fuzzy logic provides a leeway to the assessor to handle the subjectivity to allocate requisite failure probabilities.

3.13 - Benchmark Requirements for HRA Modelling

Brief comparative analyses on some of the major HRA models are shown in Appendix 2-2. In general, HRA is quite complex because of the difficulty in capturing the human mind or seeing through latent factors around human system endeavour. None of the current HRA models is without limitation, while some of the models were marred with surreptitious assumptions: lacking in practical realities, some were also flawed with un-justifiable mathematical formulations (Bedford 2001). Similarly, some data-based models are obsolete or requiring review due to advancements in technology and human capacity. It is seemingly clear that the field of HRA has been dominated by behavioural scientists because of the realisation of human cognition, which has limited the scope and the practical realities in the MMI. These are the views from many other practitioners in the field of HRA suggesting that engineers be given greater latitude to develop practical oriented human system endeavour models in the technical environment. However, this is not to say that the behavioural scientists have no place or have not contributed: indeed, it was the behavioural scientists that developed and demonstrated the effect of PSFs and have been contributing in cognitive modelling. Currently, while each of the models discussed above has a unique technique and addresses a particular area. Unfortunately, no universally accepted model exists.

Therefore, an advanced HRA model must address and encompasses, if not all, then at least some of the following concerns:

1) Human response errors in the PSA context
2) Response probability
3) Error probability
4) Success probability
5) Systematic procedure for generating reproducible qualitative and quantitative result
6) Human error failure modes in context: error proneness and potentials for error
7) Mitigation of all identified risk
8) Self audits and allowance for iteration under different scenarios
9) Documentation of assumptions, and quantification processes must be comprehensive
10) Pro-activity and all-inclusiveness i.e., individual, management, system and environmental factors must be defined

3.14 - Constraints in HRA Practices

The following were identified as constraints:

1. Historic data on human factors
2. Resources
3. Expertise
4. Representation
5. Validation of models

5.1 - Historic Data on Human Factors

Methods used in the collection of human error data are summarised below [Reason, 1990]: corpus gathering, questionnaire studies, laboratory studies, experimental studies and simulator studies.

The five methods enumerated by Reason proved effective and comprehensive however, most of the practitioners secured their data from one or two methods only. The second generation HRAs stand to benefit more in data mining from previous work and documentation. Awareness for human error documentation has increased over the last decade due to increasing awareness of human error contribution to failure. Maritime organisations around the world are cooperating in information sharing for PSA (Inozu and Radovic 1999).

Human error data bases do not provide the requisite information needed for HRA analysis and humans do not exhibit constant failure rates. Data on human contributions to accident proved difficult to find because industries deny information on the root causes and where such data exists it may be disputed by those involved (Gordon R, et al. 2005). Although different persons may cause different failures and are not likely to commit the same errors repeatedly, the data may still be useful for pattern identification of human disorderliness. Though probabilities are predictive inferences, it is imperative to understand how they are derived and how they are interpreted for application. Therefore, the accuracy of interpretation of risk in HRA is subject to accuracy in quantification which finally, dictates the risk mitigation measures.

Swain (1989) carried out a review of 14 HRA models over 50 sets of criterion and the outcome proved significant variation with the Human Reliability Assessment Group (HRAG) reviews (Kirwan B 1994). Some of the techniques being developed were for the Marine and Offshore safety assessment risk modelling (Eleye-Dotubo et al 2008). These methods tend to fit the randomness and ambiguity of human action and performance influencing factors however, they still need further validation and refinements of context.

Resources

In general, companies and organisations are often faced with resource constrains; in funding technological material, research and development, training etc. Resource constrains always hinders progress and this is the case with progression in developing HRA tool. Employing experts to evaluate human factor in organisations is with a high cost especially, if there are needs for experimentation.

Expertise

One of the breakthroughs in HRA has been the ability to identify opportunities for failures in human-system interaction via PSFs by behavioural scientists. Unfortunately, most of the HRA models were developed by the behavioural scientists even when technical systems are involved. Such models have dwelled on theories of task analysis and other surreptitious assumptions. While some scholars criticised the dominance in HRA by psychologists, others fault most of the quantification processes for having no clear mathematical justification (Byrne and Gray 2003; Bedford and Cooke 2006). This is not to say that the current HRA models cannot be utilised or that they are without merit; rather, they are in most cases developed by allocating allegorical human error probabilities without requisite technical experience and cognisance to performance conditions (Fujita and Hollnagel 2004). Unless practical-based models are developed, the realities of human contribution to failure may not be captured by modelling through quasi data, nor through experiments and simulation. Human error data has been widely criticised for the same inherent human factor in reporting, compilation or representation (Hollnagel 2000; Gordon et al. 2005; Shifrin and Tash 2007).

Representation

According to (Hollnagel E 2000), '*The notion error is vague, it only indicate cause, event or an outcome of wrong action"*. Unfortunately, given the plethora of logically different modes of human failures, axiomatisation of failure is still concentrated around human error-based failures. Others have maintained that most accident enquiries have revealed that '*bad events are more often the result of error-prone situations and error-prone activities, than they are for error-prone people*' (Reason J 1997). These error error-prone situations and activities are the disorderliness or entropy and are the *context of the failure modes*, not just the action that led to failure (Fujita, 2004) .

Validation

Model validity has been a dominant issue among the practitioners, whose efforts have been reported in various publications (Kirwan, 1983; Rose et al., 1985) e.tc. Though most of the practitioners admit that the models cannot be claimed complete without gaps, it is intended that they capture most of the known influences of human disorderliness (Williams 1988). This study observed a small number of critical challenges that are threats to the accuracy of HRA and chose to explore those threats for scrutiny in order to facilitate a new evolutionary step in HRA for the “third generation”. Human behaviour can be usual (safe) or un-usual (unsafe) defending on psychological and situational factors.

3.15 - HRA Model requirement for Maritime Application

In maritime operations, the disturbances and work demands at sea are higher than those in onshore systems. These disturbances affect crew psychology and induce: physical and mental stress due to a higher need for concentration, monitoring of parameters and hull integrity, look out over the vicinity, supervising subordinates where necessary, paper work, emerging enquiries, emergencies and incidents, listening to announcements, phone calls and alarms, thinking for systems within logistic constrains, boredom, drowsiness, aggressive sea conditions, task complexities and requirements, etc.

The challenge is in developing a high level model that is industry specific in requirement. The model must accommodate specific changes in PSFs to re-evaluate risk. Physical and cognitive components such as fatigue, workload and situational awareness are some of the PSFs such as.

1. Isolated environment (external assistance not readily available)
2. Mobile (Floating) condition- Unstable state due to sea state
3. Limited manpower – combine effort limited due to distribution of labour onboard (because each crew has his/her designated area of responsibility)

4. Space limitation (due to confined environment)

5. Difficulty in control of vessel – manoeuvrability constrains

6. Multiple incidents (fear of aggravated situation)

7. Limited emergency/repair systems/equipments/tools/spares

8. Design flexibilities and constraints e.g. poor lighting, watertight integrity, smoke, redundancy/multiple systems

9. Time criticality – response time to salvage situation critical

10. Nature of problem at hand, type of cargo etc

11. Environmental threatening factors – weather, capsize, grounding, collision, smoke, toxic substances etc.

12. Higher level of stress, workload, anxiety,

13. Higher demand on instantaneous decision making, use of initiatives

3.16 - Summary of Findings

From the foregoing discussions, Appendix 3-2 provides a brief summary on current HRA practices. And in general, the findings of this critical review are:

1. The field of human reliability is dominated by practitioners from nuclear and chemical plants. This is because of the high precision requirements, however these industries are shore-based

2. The Performance Shaping Factors (PSFs) which form the framework for HRA analysis vary among practitioners and industry of application. Though the PSFs

are a function of the plant/system being analysed, there are duplications in some applications and lack of contextual detail.

3. Some of the HRA models give little consideration to environmental factors and volitional acts are not represented in the analysis.

4. In some cases, the modelling procedure does not have any mathematical justification or validity, and lacks theoretical foundation.

5. The data used in the HRA modelling is either not adequate or lack credibility. Human error data is dynamic, and needs to be updated and be generated through suitable channels. Similarly, the data that is frequently used is either derived from a reactor safety study in 1970-1990 or in an un-natural simulation environment (simulator used to collect crew response data)

6. Some of the HRA techniques attempted to exonerate human action in their studies. 'ATHEANA and CREAM' are examples. (Hollnagel E. et al 2004) argues that '*'the PSA need to describe human performance reliability without making individual errors the pivotal concept''*. Both techniques assume the likelihood of something being done incorrectly is determined by the performance conditions rather than inherent human error probabilities. However, many of the HRA models continue to consider human error to be the main issue.

7. Obviously, it is not practicable to use particular generic models derived from a specific power plant to carry out PSA on another plant. This is basically due to differences in personnel, administrative setting, culture etc. Most HRA were developed for specific reasons and application.

8. The HRA methods must take cognisance of the criticalities of operator/crew at which the individual interacts to deliver performance result; robustness of response, safety and capability are necessary human qualities in order to compensate for environment and equipment variation.

9. The development in HRA is fast shifting to crew error identification and mitigation. Typical example are; IDAC, CREAM and ATHEANA.

10. Other limitations to the accuracy of HRA modelling are :

    a) The HRA practitioner's models are not comprehensive enough for Error Modelling (EM). This is because it usually 'fire fight' the last errors rather than anticipating and preventing the next one (Reason, 1997).

    b) There is a focus on active failures rather than both active and latent failures.

    c) There is a focus on personnel with less or no consideration to situational contributors and dependencies.

    d) No adequate distinction is reported or observed between random and systematic error-causing factors.

3.17 Concluding Remarks

The purpose of Human Reliability Analysis is to provide an account and description of human contribution to failure, quantify risks posed by humans, reduce or mitigate the human errors and document results. Human factor is wide and complex since the pattern of error may be different for different organisations and between different individuals. It is therefore difficult to make a universal or all encompassing quantification HRA model. A number of HRA models for estimating human error probabilities have been constructed and each has its own merits and limitations with varying distinction in technique and detail. The HRA models evolved through various means and each of the models is constructed to represent particular scenario(s). Similarly, the model designer's level of experience or view plays an important role in the analysis of human factor. Though the scopes of details of the HRA models have improved over time, the categorisation of first and second generation models is without any set criterion.

While none of the HRA models has universal acceptance, most of the HRA models were developed for power plants and chemical industries. Similarly, it has been observed that the field of HRA has been dominated by behavioural scientists because of the realisation of human cognition; unfortunately this trend has limited the scope and the practical realities in the man machine interface. And although the behavioural scientists have contributed immensely, such as in the realisation of PSFs and cognitive modelling, engineers must be given greater latitude to develop practical oriented HRA models. The accuracy of interpretation of risk in HRA is subject to accuracy in quantification which finally, dictates the risk mitigation measures. Limitations in the current HRA practices are quite enormous and include: lack of generic human contributions to failure data, variability in calibration, validation, industry concern, and model designers' knowledge and experience. Whilst these issues may not be easily resolved it is imperative that the premise of HRA be upheld to reduce failure and mishaps. Human reliability quantification is only a means of advice on the possibility of success or failure, where the desired goal is to achieve safety and a sustainable situation. An enduringly difficult issue is the nature of organisational factors and their influence on safety culture and how to model culture and organisational factors within HRA/PSA.

However, the HRA modelling is faced with constrains in; data, resources, validation and expertise. Any advanced HRA model must address and encompass if not all but some of the concerns such as: accurate taxonomy and context of human failure modes, proactive failure and success probabilities, management and environmental factors, risk mitigation measure and documentation etc. The criticalities in the maritime environment are quite unique compared to other industries because of disturbances, isolation and work demands at sea. These disturbances affect crew psychology and can induce physical and mental stress due to a higher need for concentration. So far, none of the HRA models addressed the human factor more comprehensibly as to capture maritime needs. Therefore, the challenge is open and that is to develop a high level HRA model that is specific for maritime application.

CHAPTER 4. Approach Adopted

4.1 General Remarks

The critical review presented in the previous Chapter on human reliability analysis techniques provided insight on the previous and current practices in human factor study. This Chapter outlines the research design (framework of approach) for the development of a Human Reliability Analysis (HRA) model for maritime application.

In the previous Chapter it was highlighted that, most of the HRA models have their origins in nuclear and chemical industries. Similarly, most of the data used for the existing models was gathered from basic disciplines through which failure probabilities were estimated. Current databases on human error are not representative of all industries or all cases due to variability in design, environment and safety requirements. As the desire to improve safety increases, industries have become more involved in the development of data on human factor specific to their need. In the maritime domain, organisations such as the classification societies, US Marine Safety Management System (MSMS), the UK Marine Accident Investigation Bureau (MAIB), Transportation Safety Board (TSB) Canada and TSB Australia etc have stepped up data acquisition. However, these data banks are not comprehensive enough due to lack of transparency, disputes among actors and other constrains such as, data source confidentiality. For instance, while compiling or documenting an accident report based on ethical principle it is not allowed to apportion blame. This will however, undermine effort to sort out the root causes of failure. Accident does not always come from single event failure, the manifestation of human error is very complex; root causes of failure especially where human are involved are often marred with technical issues (Barry

Strauch, 2004). Therefore, current human factor databases do not adequately represent human failure modes. Research carried out on maritime accidents found evidence of gross under-reporting of incidents, which also indicated volitional acts (Baker and Seah 2004; Psarros, et al. 2010; Yang, 2011).

4.2 Outline of Methodology

The method adopted for this study was conceived from the findings of the critical review in Chapter 3. Since reliability is data fixated, the reliability of any quantification lies in the reliability of the data that was used. The reliability of the data is also a function of source reliability and how accurately the data represents its intended application. The critical review clearly indicates that there are various sources of data on human factors which has been subjected to various criticisms and interpretation. Therefore, it is important to address human factor in design and operation using advance risk assessment techniques.

The methodology adopted for this research work is to exploit how to improve operational safety using a practically-oriented HRA model. Therefore, this research work will be carried out within the context of the following sections which are shown in Figure 4:1. The framework of approach was designed to exploit accident reports and develop human factors data for probabilistic safety assessment.

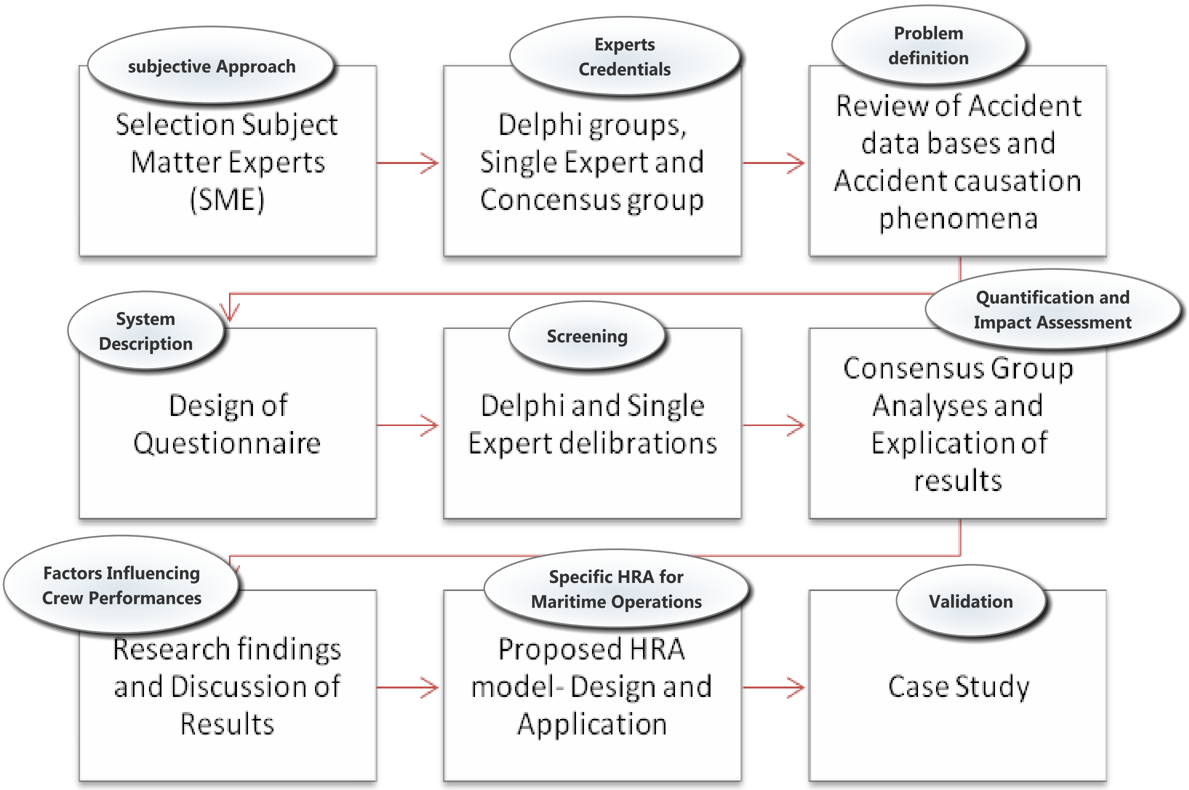


Figure 4:1- Outline of Research Methodology

The subjective approach was used in this study due to lack of original data for this application. The experts were drawn from the maritime industry, and each with no less than 10 years of experience. Details of the subject matter credentials are presented in Chapter 5. The scope and context of the human factor problems were exploited from the accident data bases and study on the accident causation phenomenon. Subsequently, with these backgrounds, a befitting questionnaire was developed for the data generation.

The Delphi and Single experts were used to screen the questionnaires and through their deliberations the feedback from the questionnaire were compiled. The review and quantification of the data was carried out by consensus group. The generic performance shaping factors for maritime operations were obtained from the results of the data following which the proposed human reliability model evolved.

4.3 Over view of Phenomenon of Accident Causation and Theories

Quite a number of theories on accident causation have been advanced which provide insight into the development of safety structures, some of which are; Domino accident theory, Ferrell concept on human factor and Peterson's, epidemiological and systems model theory (Gunter 1990): The review of these accident theories enhanced data acquisition and provided guidance understanding failure modes.

4.3.1.1 ***Domino Theory***

Heinrich's domino theory exploits the pattern of dominos falling onto another to create a chain of events. Heinrich simulates a chain of accident sequencing in five stages: social and environmental ancestry, faults of a person, unsafe conditions, accidents and injury (Heinrich, 1936; Wang 2007). Heinrich's provided a quantitative taxonomy of accident which is shown below in Figure 4:2, and in this taxonomy, it was clear that unsafe acts are top most. Over the years, no significant change was observed in this trend (Baker C and Seah 2004, Schroder-Hinrichs et al 2011).

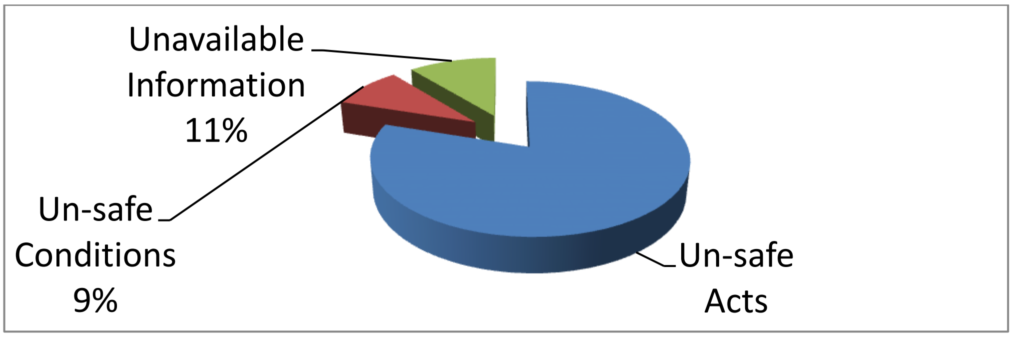


Figure 4:2 - Heinrich's Accident by Cause

4.3.1.2 ***Human Factors (Ferrell Concept)***

The human factors theory ascribes accidents to a chain of events, which are in the end caused by human error. To understand the human factors theory based on Ferrell theory, the root causes of accidents were categorised into three components: Overload, inappropriate response/incompatibility and inappropriate activities (Gunter 1990).

4.3.1.3 ***Accident/Incident (Petersen's Theory)***

The Petersen's theory utilises three generic factors: Overload, ergonomics and human or management error. The structure of this theory is shown in Figure 4:3:

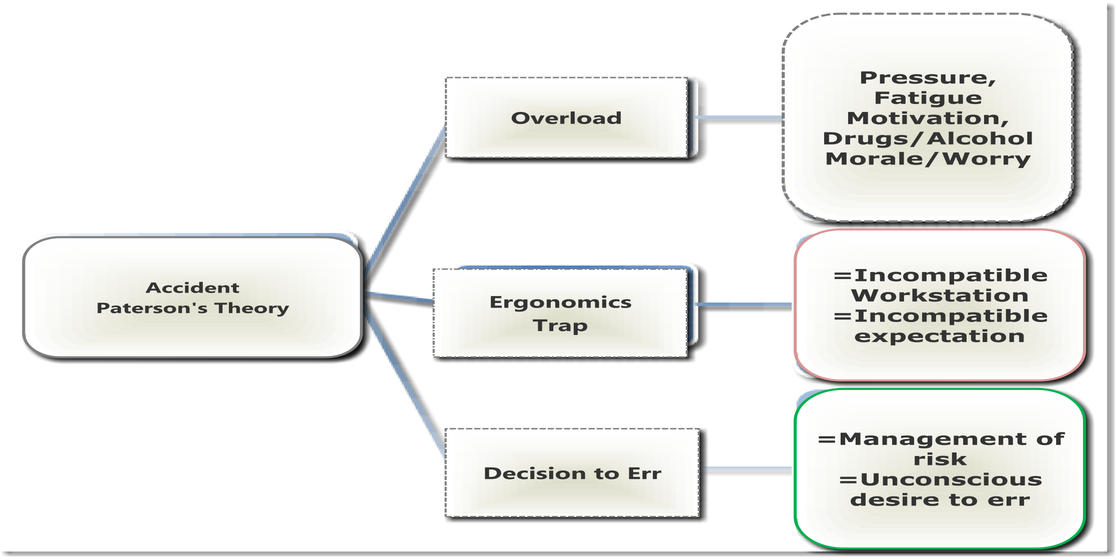


Figure 4:3– Petersen's Accident Theory

4.4 Framework for Data Mining

A study was carried on the various methods used to generate data for HRA and four generic methods were identified: Subjective, corpus gathering, experimental and simulations. Each of these methods has its merits and demerits and will be discussed in the succeeding Chapter..

The subjective method was used in this study, and this is because no reliable representative historical human factors data is available. This problem has been discussed in the preceding Chapter as one of the major constrains for the accuracy of

HRA. Unlike physical component part, humans differ from one another and do not exhibit constant failure rates. Similarly, experimental and simulator databases were refuted due to perception influence (on human belief that he/she are being experimented upon). Thus, operators tend to behave with conscious minds and increase vigilance.

Therefore, a subjective approach was adopted in three phases:

a) Delphi Method

b) Single expert

c) Group consensus

The three phase elicitation sequences were used to overcome the influence of biase which has been the main disadvantage of the subjective approach. In general, in the field of probabilistic safety analysis, the subjective approach has been the dominant source of data on risk and failure probabilities (Bedford and Cooke, 2001). Similarly, the uniqueness of the maritime operations does not provide room for real data to be developed because root causes of failures/accidents are very complex.

4.5 Numerical Analysis of Subjective Elicitations

The consensus group were used to compile and aggregate results in a more interpretable way. This allows judgement to be made on the basis of relative predictions with more confidence than can be relied upon absolute values. There are varying methods in which expert elicitations are conducted and in which experts opinion can be analysed. These methods include:

1) Bayesian Combination of Expert Assessment

2) Non-Bayesian Combination of Expert Distribution
3) Linear Opinion Pooling
4) The Classical Model – Performance-based weighting

6.1 The Classical Model

The classical statistical model is based on a single estimate on the value of the parameter and where necessary a confidence interval is generated around the estimate. The underlying principles of the classical model are: reproducibility, accountability, empirical control, neutrality and fairness. Since inception, the oldest modus operandi for interpretation of probability has been the classical model. In this research work, the classical model was considered because it matches the combination of experts that satisfied the classical model principles.

The classical model method is used to achieve rational consensus on expert's distribution and basically, is a weighted combination of expert's probability assessment. Since experts are humans, it is natural to assume that expert's experiences may be influenced in one way or the other. Hence, the weights are purely based on appropriate and strictly followed scoring rules categorisations: *strictly proper* and *reward structure*. It is imperative to operate by these rules when we are interested in elicitation. The method evolved from the doctrine of subjective probability and was built on rational decision making following Kolmogorov's probability axiom where:

The probability P is a positive (+) normalised measure over a field of possible worlds or possible state of nature (Kolmogorov 1933; Bedford and Cooke 2001).

A system of weight is based on *reward* structure and hence a score.

1. *Strictly proper* – This is a case in which subject receives maximal expected score which is the true and only true opinion of the expert, without bias or doubt of any sort. In this circumstance probabilities are referred to as *proper*

2. *Reward structure* – The probabilities elicited under reward structure are categorised as under the improper scoring rule as that:

7.1 The Beta PERT Distribution and Most Likely Value

Where a range of estimates are available, the following probability distributions may be used:

1) Uniform distribution

2) Triangle distribution

3) Beta PERT distribution

The Uniform distribution is simplest and most useful where only minimum and maximum values are available. Where a likely estimate value is available in addition to minimum and maximum values, triangle distribution can be constructed. In the triangle distribution, the most likely value will be the mode and at the point of the triangle. The beta PERT or PERT (Programme Evaluation Review Technique) distribution as it is popularly called, as with other probability distributions is a useful tool for modelling expert's data (Vose 2008). The usefulness and quality of the prediction is limited to the quality of the inputs (expert's score). The accuracy of the forecast depends upon the quality of the experts. PERT is similar to the triangle distribution and both use most likely value. Unlike the triangular distribution, the PERT distribution yields a smooth curve around the most likely value. In this study, five Delphi groups and four single experts' results will be used in the first instance and final result will be rounded up by consensus group. In principle, since every rational individual has his/her subjective probability, it was deemed necessary to reach consensus. Therefore, the use of the Consensus group was to round up.

4.6 Qualitative Analyses of Results

The results obtained from the data analysis were subjected to qualitative analyses with a view to understand how the human factor manifests in operations. This will enable design of appropriate HRA tool which will capture all the divergent influencing factors for maritime applications. Since failure rates are not characteristics of humans, it is not feasible to allocate absolute numerical values as human error probabilities, the performance shaping factors with associated error prone situations have to be utilised for predicting human factor.

Performance Shaping Factors (PSF) are essential in determining and understanding the root causes and opportunities for manifestation of failure. The taxonomies of Performance Shaping Factor (PSF) are so developed as to be suitable for a specific purpose and application. The set of PSFs considered for HRA is slightly different and entirely depends on the quantification procedure designed by the analyst. One of the major causes of drift to faulty HRA is the direct usage of PSFs absolute probability values without qualitative explication. Each of the PSFs have continuum of discrete utilities which need to be accurately represented with probabilities. For instance; in evaluating Procedure, we need to look into whether or not:

1) Are both normal and emergency operational procedure are available or only one of the two is available?

2) Are there signs, tags, labels etc that could guide the crew for a safe operation?

3) Are there procedure for documentation and reporting of defects, alterations and additions?

Each of these mentioned utilities are derivatives of procedure and each can impact independently or otherwise on crew. Therefore, the decomposition of each PSF is imperative for greater precision in predication and mitigation in HRA. The Hypothetical Construct Variables (HyCs) were developed as derivatives of the PSFs and each were assigned impact probability factor. The HyCs utilities were used to develop an excel software programme following the sequence in Figure 4:4

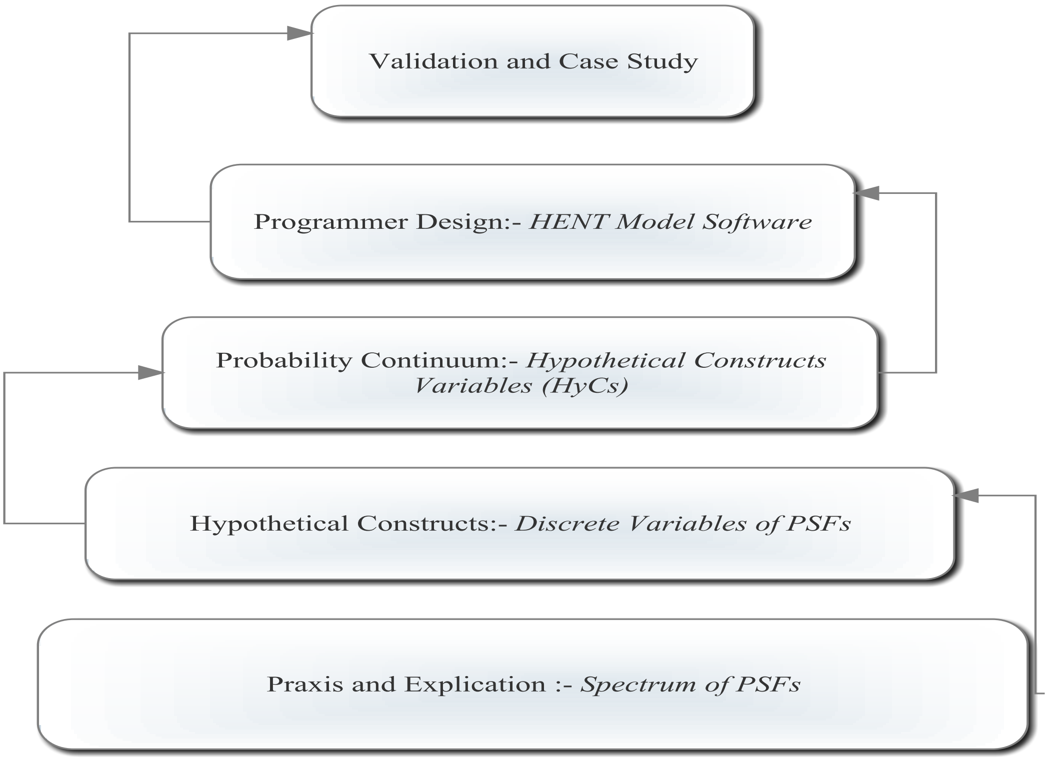


Figure 4:4- Sequence of human entropy development

4.7 Design of the Proposed HRA Model

As there are different kinds of human reliability assessment tools so also, there exist various kinds of quantification methods such as fault tree, event tree, mathematical models etc. Over the years these reliability modelling techniques have been developed using numerous software tools which enables predictions to be revisited frequently. Unfortunately, unlike component failures, human do not exhibit data driven fixed failure rates. Similarly, in both the fault and event tree, representation of dependencies among causal factors is not feasible in HRA because of complication. There is no evidence that these modelling techniques can produce greater precision in human reliability than existing predictions based on hardware component failures. Human modes of failure are dynamical and the concept of data validity and repeatability is highly controversial. As a result, it can be concluded that a simplified HRA assessment tool with capability to store, print and edit result must be sourced. In addition, such modelling tool must be able to support iterative and quantitative analysis.

Therefore, in view of the above argument, a befitting software programme which could fit the proposed model was chosen. The taxonomy and explication of PSFs into hypothetical construct variables was found suit into the Excel programme known as Visual Basic Application (VBA). The programme can be used to manipulate macros which thus, made it inherently flexible and its ability to audit results is utterly remarkable.

4.8 Outline of VBA capabilities are:

1) Automating recurrent and repetitive tasks – this involves the macron can be run to reproduce and update recurrent results in an auditable format.

2) Automatic run of macro – the macro can be programmed to run in an auto format.

3) Creating customised worksheet function – creating you're a customised worksheet function, is known as 'user defined functions'. This functionality can allow custom calculations that are not available in an Excel's built-in function.

4) Simplification of workbook's look – the workbook's look can be simplified for others to use even without knowledge on Excel. Customised and friendly-user menus interfaces can be built to guide users through the workbook.

5) Controlling other office applications – The VBA supports the applications of other office programmes to be controlled from Excel such as; importing table from Access into Excel worksheet, VBA can automate the process.

Despite these remarkable and resourceful advantages of the VBA, it is however not without its limitations. While not all companies embrace VBA programme, Microsoft may add or remove VBA commands in any of its subsequent versions of Excel at discretion without notice. Similarly, the VBA programme may not run uniformly in all computer environments; it often produces code error with other users.

4.9 Case Study and Validation

Since validation of HRA model is seemingly futile because human error probabilities are not fixed, efforts were made to carry out case study to assess the results against current practices. It was noted in the past that, most of the HRA models concentrated on cognitive errors and ergonomic slips, however, recent findings suggests that volitional acts dominated human contribution to failure. Similarly, literature review has indicated that over 70% of accidents were caused by humans, in this study; the initiative is to prove that current human failure modes constitute over 70 % of accidents as the datum for validation. This will be achieved by using the results obtained in the data mining and input same to the proposed model.

A case study was also undertaken to gauge the performance and effectiveness of the resources of the model. Because human failure cannot be precisely predicted, the models only provide guidance for safe operations and highlight on potentials for error proneness. Potentials' for human error are the operational gaps which involve crew, management and environment for instance: personnel risks which may develop due to complacency, low morale, health state or management tendencies such as: profiteering, over reliance's of crew to deliver without adequate logistics etc. Therefore, the case study was carried out so as to demonstrate the wherewithal of the new HRA model and to reveal how the PSFs utilities can be used to predict human performances. This is a practical based approach and requires assessors with field experience.

4.10 Concluding Remarks

Operational constrains for HRA are enormous and quite challenging. Tackling the gaps in the existing HRA techniques requires in-depth knowledge and experience in the domain of human reliability and practical systems thinking. However, preventing failures in operation can only be accomplished by understanding and removing or managing the causes of instability.

The approach in this research work is based on practical realities and the knowledge derived from the critical review in the preceding chapter was used judiciously in understanding the theories of error/failure. Statistical theories used in the HRA domain were investigated and the classical model was sort as most appropriate. Given the complexities in human contribution to accidents it was deemed imperative to embark on subjective analysis on accident phenomenon and search for root cause. The classical model is a performance based weighing model and was considered in order to achieve-rational consensus on expert's distribution. The beta PERT distribution was used to obtain a normalised most likely value of the estimates because it can generates smooth curve that progressively attaches more emphasis on the most likely value. The Visual Basic programming was adopted for use in the model design because of its rapid application development of graphical user interface capability and ease of usage.

CHAPTER 5. Data Mining

5.1 Introduction

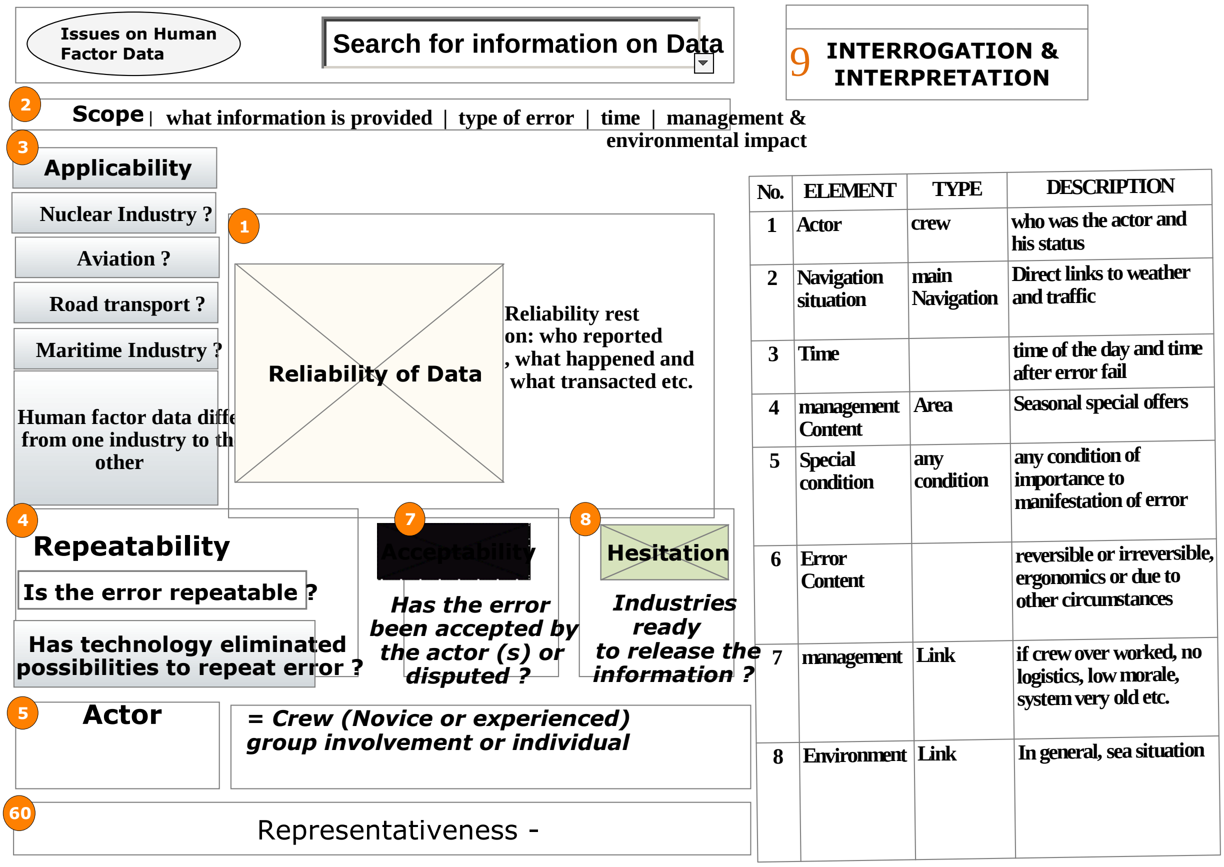
Following the critical review and the outline of approach to be adopted, this Chapter presents details on the data mining for this study. The critical review from the preceding chapter provided insight into the data requirement for HRA. Therefore, the need to generate data on human factor is necessitated by the demand to account for accurate assessment of human failure modes to improve system and environmental safety. As the accuracy of risk assessment relies on data, it is imperative to design a robust and transparent method of reviewing past events to extract relevant information (David G. 1994).

Various methods for generating and compilations of data were reviewed in this study, however, the subjective method was deemed appropriate for HRA data. The subjective approach is most appropriate because in the context of risk management, expert opinion plays a key role in the development of quantitative data; it is used to assess model parameters (Bram Wisse 2008). Expert opinions are also used in anchoring qualitative and balancing quantitative data for human reliability e.g. in nuclear regulatory commission, SLIM-MAUD, APJ etc, novel techniques have been developed for analysing experts' elicitations as discussed in the critical review (Savage LJ 1971; NRC 1975; Embrey, Humphreys et al. 1984; Cooke 1991; Kirwan 1997).

5.2 Human Error Data- Issues

Over the years, major accidents have taken place and subsequent investigations have traced generic root causes to human factors. This is especially the root cause of most well known and major historic mishaps such as ; MV *Dona Paz, 1987,* Chernobyl, 1986, Exxon Valdez, 1989, Three Mile Island, 1979, Al-Salam passenger liner, 2006 and the BP Oil spillages, 2010.

The data and information gathered on the failure modes of these accidents varies from one analyst to the other depending on the source, access to information and intended use. This makes data mining on human factors very complex and so; where such data exists it is surrounded with questions concerning its reliability and interpretation as indicated in Figure 5:1.



No.	ELEMENT	TYPE	DESCRIPTION
1	Actor	crew	who was the actor and his status
2	Navigation situation	main Navigation	Direct links to weather and traffic
3	Time		time of the day and time after error fail
4	management Content	Area	Seasonal special offers
5	Special condition	any condition	any condition of importance to manifestation of error
6	Error Content		reversible or irreversible, ergonomics or due to other circumstances
7	management	Link	if crew over worked, no logistics, low morale, system very old etc.
8	Environment	Link	In general, sea situation

Figure 5:1 - Issues Beclouding Human Error Data

1. Reliability – The reliability of data generated is subject to criticisms on the basis of possible biasness as to the true root cause of failure. Volitional acts may be represented as errors, engineers may attribute failures to procedure or technical

issues, and a psychologist may only look at theoretical causes in cognitive failure mode.

2. Scope of detail of error (circumstances) – The current human error data are limiting in scope and details. Classification of error must be linked to the operational state of plant and according to the prevailing exigencies. This is however, not the case in most of the human factor databases. It is of paramount importance to specify how the data obtained and at what circumstance otherwise; the data cannot be interpreted by a third party.

3. Applicability – Human error data is plant specific due to varying operational conditions e.g. nuclear plants and the aviation industry operate with greater precision (because of limited time to repair in operation before disaster is escalated) as compared to the maritime industry. Human error data obtained from nuclear plants cannot be applied to quantify human error for maritime operations and vice versa. Therefore, human failure data is plant specific

4. Repeatability – One of the major disadvantages of human factor database is that, repeatability of the same error may not be guaranteed. Each individual may have his or her failure mode depending upon the prevailing circumstances.

5. Actor - Information stored in human error data bases does not cover or provide details on the status of actor(s) involved e.g., errors made by a group, novice or expert are lumped together without explication.

6. Representation – Data on human error is not adequate to represent all conditions since human failure modes are always changing in pattern. Data may not represent or provide a clear picture on the manifestation of failure.

7. Acceptability – The data on human error is seldom refuted even by the parties involved in the accident. No one is ready to accept blame and so results of an enquiry or investigation are always contested by the parties involved

8. Hesitation – Individuals or groups involved in failure always have a tendency to cover up their lapses and may not report an incident as it occurs. Similarly, most industries tend to keep secret information on accidents or failures due to human error, to cover up organisational lapses

9. Interpretation and categorisation – There has been no categorisation of error type or how it manifests. This is difficult to achieve since categorisation is entirely in the hands of the assessor and since failure is viewed differently by different individuals

The concerns which are illuminated above have been reported by various practitioners in the field of HRA (IAEA 1990; Gordon et al. 2005). In order to understand human error data, it is also pertinent to understand human factors as composed of human error and other forms of human behaviour in the form of violations.

5.3 Overview of Generic Methods Used to Generate Data

“The ability to predict future occurrences lies in the past observations on past events and accuracy of recorded information. While solving the forward problem, to ignore or overlook at the competing phenomena in the form of data (records of past events) without which results may be flawed. Five generic methods of data mining have been enumerated from various studies and which proved effective and comprehensive. Since no universally accepted method is the best, any one, two or three of the methods can be utilised “(Reason 1990).

Although data on human factor can be found in various industries and organisations, the data cannot be universal. This is because methods used to generate or compile the data differ from one organisation to the other. The general standard methods used in data mining are shown in Figure 5:2.

1. *Corpus Gathering* – Identification and description of naturally occurring phenomena. It provides a reasonably comprehensive qualitative account of the available species of error. Natural history techniques are excellent for providing a wide-angle view of phenomena but often raise more questions than they can answer

2. *Questionnaire Studies* – Through self-report questionnaires, descriptions and answers to various incidences can be perceptually established. Experience is rated quantitatively or qualitatively for slips, lapses and misses

3. *Experimental (Laboratory) Studies* – Experimental studies may be a consequence of naturalistic observations and tend to justify observations. This is a powerful technique for studying mechanisms through deliberate elicitation of particular error type under controlled laboratory conditions(Bears 1980):

4. *Simulator Studies* – This involves the use of a computer to simulate real life dynamic features of a particular system of interest. The system is created on a computer programme within the laboratory and results of the simulation can then be evaluated

A summary on the strengths and weaknesses of all the methods used to generate data are provided in Table 5-1.

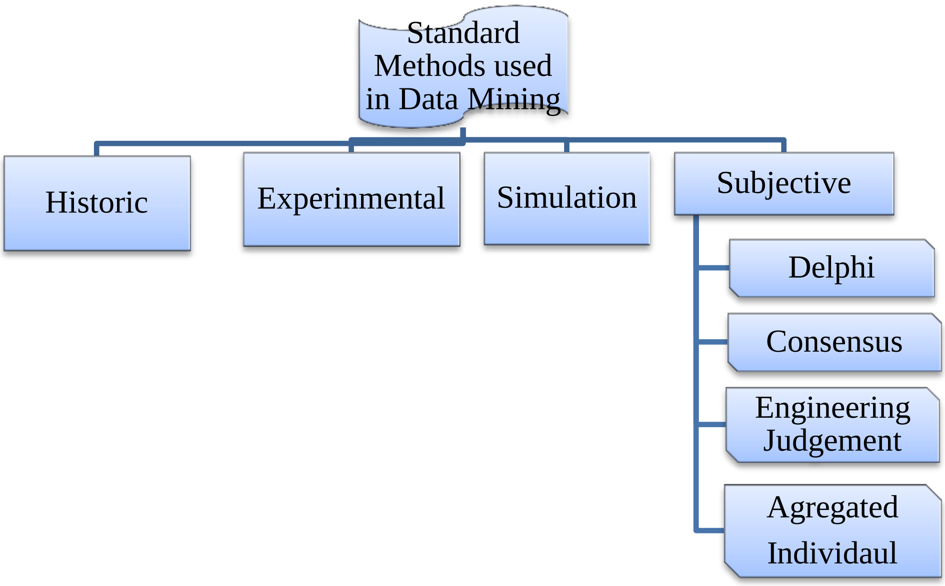


Figure 5:2 - Techniques Used in Data Mining

Table 5-1 - Comparative Analysis of Techniques Used in Data Mining

Technique	Methodology	Strength	Weakness
Historical	Generated by documentation/records or observation over time	Descriptive data, more accurate and Flexibility for interpretation. It has been basis for research and development	Data may be censored, suffer omission or outdated
Experimental	Through practical experimentation by representation of parameter	Repeatable and generates both qualitative and quantitative	This method is also to human error, or bias and may produce artificial result
Simulation	Imitation of the operation of a real-world process or system to generation an artificial history of the system (data).	Detailed study possible, flexibility, visualise results	Assumptions, biasness, expensive

Consensus	Each contribute and final judgement by consensus	Best for new and untried technology. The method potentially covers all questions that often had scant empirical data.	Personality variable and bias prominent
Delphi	Experts make anonymous assessments and receive feedbacks. Which are re-assessed and aggregated by facilitator	Biasness eliminated and feedback and review is achieved.	No discussion among experts
Aggregated Individual t	Single expert assessment based on proven professional expertise	Assessments are statistically aggregated, no biasness.	No sharing of experience or expertise

The Delphi forecasting method was developed so as to overcome the shortcomings of human judgements in forecasting and the method can be used for any application which a committee can be used (Gordon and Hayward, 1968; Harry et al. 2000). Similarly, Delphi is a better option than face-to-face interaction groups which is prone to biases, and are appropriate for the development and assessment of ‘criteria’ and ‘objective’ (Dalkey, 1971). Delphi superiority over other subjective techniques has been highlighted in many research studies (Erffmeyer, 1984; Armstrong, 2001; Goodwin et al. 1998).

The outline of Delphi criteria and its merits are (Armstrong, 2001):

1. In Delphi elicitation, 4 to 20 experts with domain knowledge can elicit

2. Experts must have normative knowledge and experience
3. Facilitator appointed
4. 2 to 3 rounds to be conducted
5. Individual experts receive feedback of average estimates
6. Summarised by weighing all experts' estimates equally
7. Anonymity and iteration is achieved

Some of the shortcomings of the Delphi method lie in gaining the attention of requisite subject matter experts and the associated experts' high costs. Similarly, critics have argued that not all of the questionnaires will be returned and the claim of accuracy was also challenged (Brockhoff, 1975).

5.4 Conduct of the Data Mining Exercise

In the preceding Chapter, details of the subject matter experts and groups were provided and the composition of the SME is shown in The data mining procedure was carried out as follows:

5.4.1.1 *Profile for Subject Matter Experts (SME) –*

As one of the prerequisite for the Delphi method, facilitators were appointed for each of the five Delphi groups listed above. The SMEs were carefully selected from the maritime industry with the following composition and profile as shown in Table 5-2:

Table 5-2 - Subject Matter Experts profile

Subject Matter Experts Profile for HEBC Elicitation					
Expert Group	Group Size	No.of Rounds	Mean Years Experience	Age group	Position
Single (E1)	1	2	30	46-55	CTOP
Single (E2)	1	2	23	36-45	FSMEO
Single (E3)	1	2	22	36-45	Chief Engineer
Single (E4)	1	2	10	36-45	Captain
Consensus Group (C1)	4	2	18	36-45	D-Ops Chairman
Consensus Group (C2)	3	3	20	36-45	DSDA Chairman
Delphi (D1)	9	2	18	40-50	CI-Nav - Facilitator
Delphi (D2)	6	3	22	36-45	Chief Engineer - Facilitator
Delphi (D3)	5	2	22	36-45	D-Ops Offshore - Chairman
Delphi (D4)	4	2	15	31-40	CI-Comm- Facilitator
Delphi (D5)	4	3	20	36-45	Captain - Facilitator

Where:

- CTOP – Chief of Operations (highest position in fleet operations)
- CI-Nav- Chief Instructor, Maritime Navigation School

- CI-Comm – Chief Instructor, Maritime Communications School
- FSMEO - Fleet Support Marine Engineering Officer
- DSDA - Director Ship Design and Acquisition

The Delhi and Single experts groups deliberated upon accident reports and developed a querying tool. In the review and study of accident reports, accident causation theories were studied as guidance to the development of appropriate questionnaire. Subsequently, after brain storming relevant questionnaire to the field of study was designed to capture all the concerns.

5.4.1.2 *Review of Maritime Accident Reports*

At the initial stage it is crucial to determine what important information should be given to experts to refresh their minds. In order to gain insight into the nature and role of human element in the causation of accidents, maritime accident databases were circulated to the experts. Therefore, experts study the maritime accident databases which were drawn from MAIB, US Coast guard and other related industries.

To determine the root causes of failures, accidents reports were interrogated to determine: manifestation of failure, diagnostic pathway, recovery pathways and the fail event. The Nuclear Energy Agency data querying model comprising of nine questions were used as guidance (NEA 1998) to draw up questionnaire. In the nine question model, the task, person, action and organisational contributions to the accidents were investigated. Similarly, the mode of communication, those involved and time to failure were sorted out with the aid of the nine question tool. The nine question model guidelines on the extortion of human error are shown in Figure 5:3.

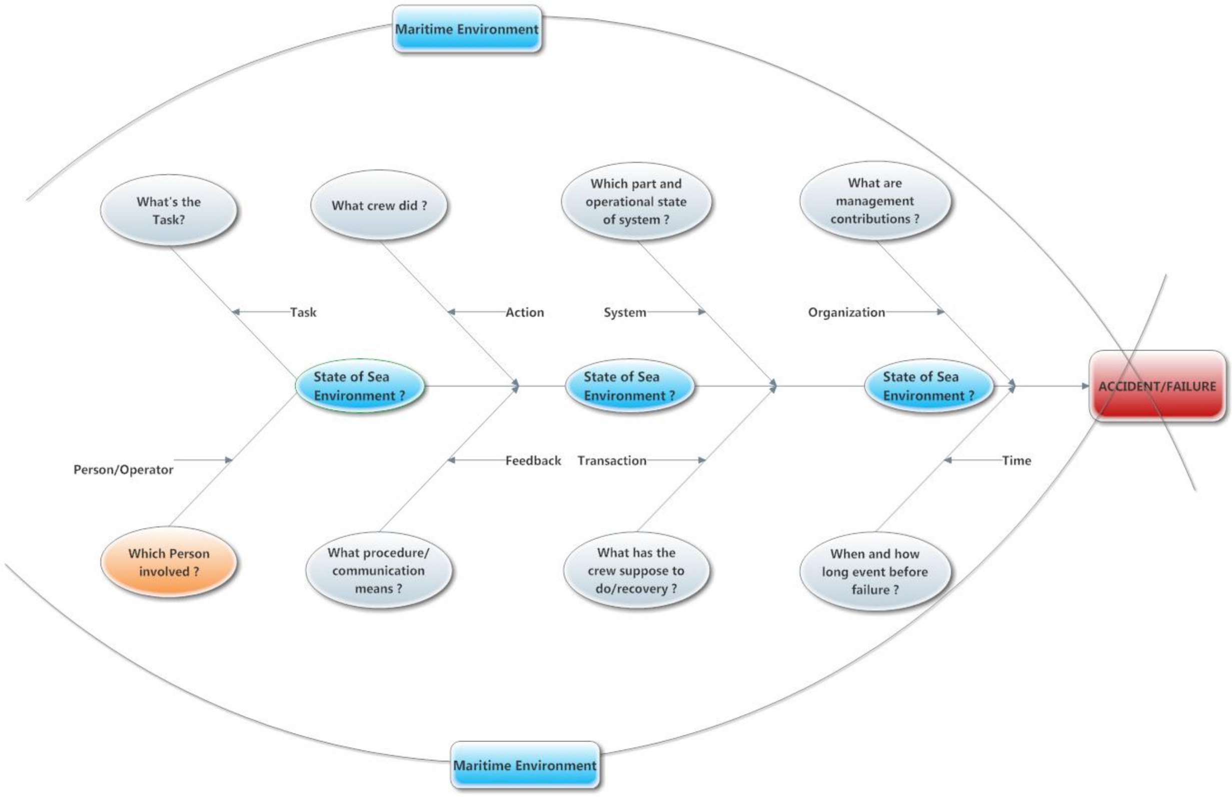


Figure 5:3 - Nine Question Model Guidelines on HE Assessments

Quick review was conducted which investigated characteristics of maritime accidents, types of accidents, causes and consequences. Human reliability analysis does not only identify problems but also seeks reasons and ways to reduce risks. In this study, all possible diagnostic and recovery pathways were also considered in the investigations. Therefore, the data bases were interrogated for the retrieval of relevant information in order to design frameworks for the appropriate HRA data.

5.4.1.3 *Design of Questionnaire*

The Likert scale was used in the questionnaire since it has the advantage of allowing the expert to cater for uncertainty with confidence bounds. The questionnaires were circulated and left with the experts for a period of 25 days. As a response, assessors specify their levels of agreement along the range of scale as shown in Table 5-3. In this case, each progressive Likert score is better than the preceding value.

Table 5-3 - Likert Scale Model

Likert Scale	00-09	10-30	31-50	51-70	71-90	91 -100
Designation	Negligible	Little Importance	Moderately Important	important	Very Important	Most important

Experts scored in the form of rating various factors of their importance, to which each condition can, independently, impact positively on human performance in operations. The score was measured on Likert scales which provided the confidence bounds (Likert 1932; Muruki 1990).

The Likert scale has the following advantages:

1. It reveals the assessor's strength across all questions
2. It eliminates yes or no answers
3. Data is easy to analyse
4. Collection of data is simplified
5. The process is quicker
6. It allows the assessor to compensate for his doubts.

The questionnaire was divided into two parts: part one is qualitative on a Likert scale as shown in Appendix 5-1 while, part two is quantitative and the experts have the liberty to input his or her opinion, as shown in Appendix 5-2.

5.4.1.4 *Expert Scores*

Information collected and processed in several deliberations and in doing this, over 600 incidents and accidents were reviewed. The data bases were obtained from MAIB, US Coast guard (data which was used by SAFECO project) and locally sourced information. Experts score in the form of rating factor of importance to which each condition can, independently, impact positively or negatively on human performance in operations. The elicitations were coordinated follows:

1. Questionnaires from the Delphi groups were collected as feedback and then experts assembled to discuss results before facilitators. The results were rounded up by rating each condition with an impact factor

2. The single expert's scores were collected and compiled. The frequency of occurrences for each score was noted.

3. The frequencies of the Delphi and single expert's scores were aggregated to obtain cumulative frequencies.

4. In all cases experts gave their opinion on the percentage of human contribution to accident in maritime industry

5. The Consensus Group's elicitations were similar to that of the Delphi method but without a facilitator. Each expert contributes to the deliberations. Final judgement is reached by consensus

6. The consensus group rounded up scores on modes of human failure (error and volitional acts) in marine operations

5.5 Elicitation Results

The elicitation provided rational judgement based on group and individual appreciation of the particulars of the performance shaping factors variables. The application of a consensus group was to supplement for the hard technical evidence provided by the Delphi method and Single Experts. Both methods were used in exploiting the un-quantified characteristics of man Machine Interface (MMI) to numerical data suitable for practical problem solving.

Table 5-4 provides the summary of results for the performance shaping factors obtained from the elicitations. A total number of nine performance shaping factors were identified as the human influencing factors in maritime operations (Turan and El-Ladan 2012). The frequencies of each score corresponding to the method used are also displayed in the table. The results are arranged according to rank, and the cumulative frequencies (C-freq) of scores are shown in the last column. The C-Freq indicates the strength of the expert assessment (number of times each number is voted by the experts). Detailed results for the elicitations are shown in Appendix 5-3.

Table 5-4 – Summary Elicitation Results

Performance Shaping Factors (PSFs)	Delphi scores		Single Expert		Scores by Rank and Cumulative frequency	
	Score	Frequency	Score	Frequency	Score	C-Freq
Training	95	1	80.5	2	95	1

	80.5	3	60.5	2	80.5	5
	60.5	1	-	-	60.5	3
Welfare	80.5	2	60.5	2	80.5	3
	60.5	2	40.5	1	60.5	4
	40.5	1	80.5	1	40.5	2
Logistics	95	1	40.5	1	95	2
	80.5	2	95	1	80.5	4
	60.5	1	80.5	2	60.5	1
	40.5	1	-	-	40.5	2
Quality of Crew	95	2	60.5	1	95	4
	80.5	2	95	2	80.5	3
	60.5	1	80.5	1	60.5	2
Stress	80.5	1	60.5	3	80.5	2
	60.5	2	80.5	1	60.5	5
	40.5	2	-	-	40.5	2
Procedure	95	1	60.5	3	95	1
	80.5	2	80.5	1	80.5	3
	60.5	2	-	-	60.5	5
Communication	95	1	80.5	2	95	1
	80.5	1	60.5	2	80.5	3
	60.5	1	-	-	60.5	3
	40.5	1	-	-	40.5	1
	15.5	1	-	-	15.5	1
Supervision	95	2	80.5	2	95	2
	80.5	2	60.5	2	80.5	4
	60.5	1	-	-	60.5	3
Environment	80.5	1	60.5	2	80.5	1
	60.5	2	40.5	2	60.5	4
	40.5	2	-	-	40.5	4
Human Contribution to Accidents %	92.5	3	60.5	2	92.5	4

	77.5	1	77.5	2	77.5	3
					60.5	2

Tripartite human failure modes were uncovered; Breach, Cognitive error and negligence. In the review of accident data bases, subject matter experts assessed the frequencies and pattern of the types of maritime accidents. The maritime accidents which were particularly reviewed are: Fire, Explosion, Collision, Stranding, Capsize, flooding and Grounding. The generic root causes of these accidents were identified and categorised according to human failure mode (Cognitive error, negligence and breach). The categorisation of these accidents into human failure modes uncovered the tripartite failure modes shown in Table 5-5. The results were rounded up in percentages as follows:

1) Breach – 17.4%
2) Cognitive error – 22%
3) Negligence – 60.1

Therefore, in addition to cognitive error, each of the group identified volitional issues as major contribution to accidents. These volitional issues are negligence and breach (no act of sabotage is considered). As a consequence to this discovery, the generic human performance shaping factors for maritime operations were called Human Entropy Boundary Conditions (HEBC), the detailed taxonomy is at Appendix 5-4 (Turan and El-Ladan 2012). The HEBC evolved because of the finding on the pattern of human failure mode and it signifies operational influencing factors due to crew disorderliness.

The consensus groups were used to review and develop the hypothetical constructs variables for the HEBC. The Hypothetical Constructs (HyCs) variables explore the structural knowledge of the HEBC which will be presented in subsequent Chapter.

Table 5-5 : Summary of Findings on Generic Human Factors

Serial	**Incident**	**Impact Factors by Human Failure mode derived by SME**		
		Cognitive error	Negligence	Breach
1	Fire	3	12	4
2	Explosion	6	4	0
3	Capsize	1	1	0
4	Collision/Contact	2	9	3
5	Stranding	1	7	1
6	Grounding	4	7	3
7	Flooding	2	8	2
8	Leak/Spill	1	8	3
∑ **Sum of Failure Modes**		20	56	16

5.6 Definition and Explication of Tripartite Failure Mode

"There is no risk without people; as complex and erratic beings, humans interacting with and working as part of a technological, organisational and psychosocial system will inevitably produce variability, risk and, sometimes, error" (Kelvin Top-Set 2009).

It is therefore, necessary to make qualitative appraisal of the under listed human factors; the tripartite human failure mode .This is important in deciding where the boundaries of the problem should be set and to identify secondary and primary errors. The *raison d'être* for the tripartite failure mode is shown in Figure 5:4 below. Whilst, these human failure modes are inexhaustible but, the following possibilities were hypothesised:

5.6.1.1 ***Cognitive Error (Individual human error)***

Cognitive Error (CE) is basically due to mental judgemental failure or lapse in cognitive consciousness. It is the human inability to see, perceive or remember. Cognitive failure can manifest in the form of slips, fumbles, mistakes, lapses in skill, rule or knowledge-base mistakes. Failures due to cognitive error may be recovered if the victim is prompted in good time and the system can be reverted. Cognitive error can be triigered by any of the following situations:

1) Slips/lapses/fumbles and other forms of misjudgement
2) Stress at work especially in complex task environment or un-maintained system
3) Environmental criticalities (Influence of harsh environments)
4) Hidden design defects (revealed in operations or influence of ergonomic)
5) Emerging health state
6) Mental judgemental failure

5.6.1.2 ***Individual Negligence (Extraneous acts)***

Negligence is the failure to carry out duties in a safe manner or act without due diligence. It is lack of strict adherence to safety procedure, or failure to exercise a reasonable degree of care. Negligence may be as a result of boredom, tiredness, low morale or as a result of clumsy procedures. As a result, the individual crew may disregard procedure, make assumptions, take risks and refuse to exercise reasonable care in the circumstances. Negligence may be due to:

1) Lack of concern or attention to detail
2) Skip some safety regulations
3) Assumption of something with potential risks that could cause failure e.g. poor lighting, heat, noise, malfunction etc.
4) Familiarity factor in taking/handing over duty e.g. not paying attention to special instructions, or improper handing over watch etc.
5) Fail to report observed maintenance lapses/breaches
6) Fail to report health state/stress/mental state (drugs, alcohol.)
7) Wrongful hazard perception /misjudgement of risk
8) Inadequate communication/feedback (information, handing/taking over)
9) Fail to complete tasks that are time critical

5.6.1.3 ***Breach (Bounded rationality)***

Breach are acts of conscious law breaking, and in this case it is assumed that no intention to cause harm/sabotage. Breaches may be in the form of corner-cutting, with or without aim of benefit. Breach may be in the form of trade-off of thoroughness for efficiency with a view to maintain system persistence, acquire more profit or as trial and error approach,

1) Violations due to the presence of latent factors e.g. group influence, trade-off of thoroughness for efficiency etc.

2) Management refusal to train crew commensurate to job status

3) Lack of motivation (promotion, welfare etc.)

4) Poor maintenance (culture/cost-based/contractual issues)

5) Wrong selection/recruitment of staff/crew and manning

6) Fail to monitor physical and psychological state of crew/staff

7) Industrial competition factors

8) High work load/disturbance/insufficient manpower

9) Lack of Research and Development (R&D) to improve safety, reliability predictions

10) Fail to provide good working environment (safe guards, lighting, vibration etc)

11) Poor safety culture and supervision

12) Poor documentation (written procedure)

Even though, these hypothesised human failure mode utilities are difficult to sort, and inexhaustible it remains paramount to acknowledge the manifestation and duty bound to account for all utilities in HRA. However, these volitional issues were not adequately represented in most of the HRA models. Safety measures are aimed at achieving the desired safety, not just to quantify the risks, and hence should indicate which variable should be changed in order to restore the desired level of safety. Since the evidence and causes of human error are generally qualitative, human reliability models should be flexible in context to account for situational adaptations and to enable control of what is controllable.

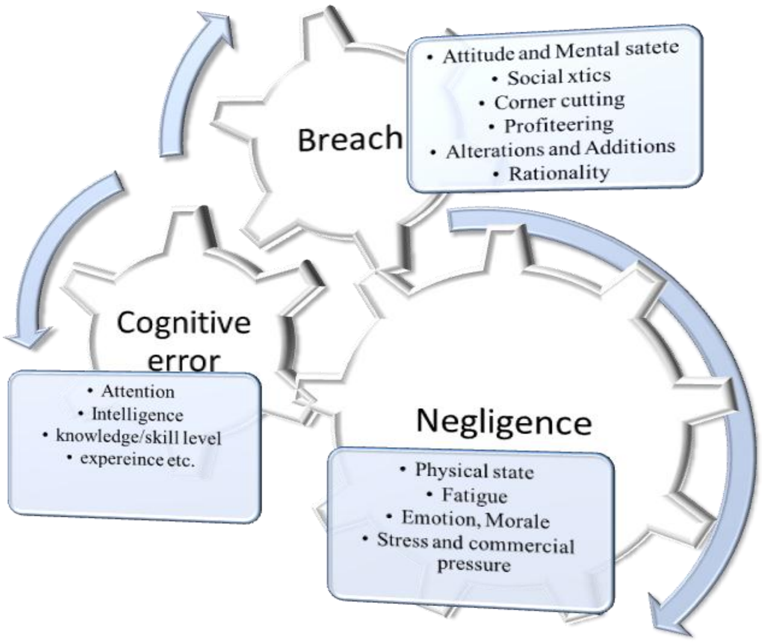
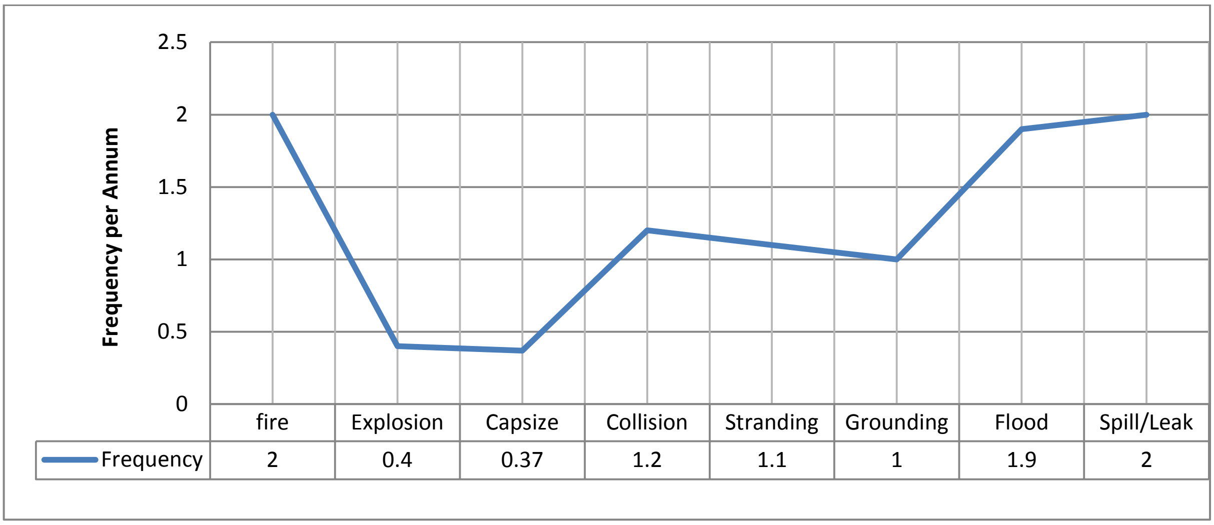


Figure 5:4- *Raison d'être* for the tripartite failure mode

There are various data bases which were garneted from different regions and each with varying application. That notwithstanding, in this study, the review was carried out on Sea going vessels (at sea and in harbour) and the expert group sorted out what might constitute unreliability in the data. Similarly, subject matter experts rounded up results on the frequency of occurrences of accidents per annum as shown in Figure 5:5 (Military data source). Analyses and reports from the accident data bases have also clearly indicated that most of the maritime accidents and fatalities were due to negligence. While this is not an isolated case, the result goes well with all other year (El-Ladan and Turan, 2010).



	fire	Explosion	Capsize	Collision	Stranding	Grounding	Flood	Spill/Leak
Frequency	2	0.4	0.37	1.2	1.1	1	1.9	2

Figure 5:5 – Average Maritime Accident Frequencies per Annum (Classified Military Data)

5.7 Concluding Remarks

Data mining in human factor is complex and a tedious exercise because of a number of issues surrounding the subject- *human factor*. Over the years human reliability practioners secured data from corpus gathering to build HRA models. Unfortunately, overtime such data has become obsolete due to improvement in technology and man power training which is designed based on previous antecedences. The subjective method on data generation proved more reliable in the study of human factor because it enables manifestation of failure to be thoroughly interrogated and the experts add on to own experiences. The experts were drawn from the maritime industry and each with proven experience of not less than 10 years. The elicitation was divided into three categories: Delphi method, Single expert and Consensus group. Both methods were fully utilised and peer review was conducted to refine the information.

The Delphi method which support cross examination was extensively used at the onset of the exercise. Human failure pattern was investigated through available accident data bases obtained from maritime industry such as; MAIB, United States Coast guard etc. The elicitation uncovered tripartite human failure modes in the form of: Cognitive error, negligence and breach. Nine generic human performance shaping factors were identified and which are called Human Entropy Boundary Conditions (HEBCs) because of the discovery of tripartite failure mode. The HEBCs are Crew quality, training, supervision, procedure, communication, welfare, logistics, stress and environment. Each of the HEBCs were identified with a scale derived from data and reviewed by the subject matter experts. Human reliability analysis does not only identify problems but also seeks reasons and ways to reduce risks. Therefore, all possible diagnostic and recovery pathways were also considered and exploited in the investigations. The data generated was subjected to rigorous screening by the consensus groups for the retrieval of relevant information in order to design frameworks for the appropriate HRA data. Further qualitative and quantitative analyses on the data mining results are provided in the next Chapter.

CHAPTER 6. Analyses of Results

6.1 Introduction

This Chapter presents the research milestone findings; Human entropy and the Human Entropy Boundary Conditions (HEBCs). The data obtained is non-parametric because it does not come or satisfy any parametric distribution. A number of non-parametric data model tools are available such as; lognormal, Normal, Beta, Weibull, Pareto, log-logistics and triangle distribution etc. The scoring, validation and analyses of the data was subjected to scrutiny, empirical control, neutrality and fairness as provided by the provisions of the methods used. The rationality is translated into workable procedure which gave convincing results following guidance works provided in the 'Classical Model' (Cooke 1991; Bedford T and Cooke R 2001; Aspinall 2008). The application of consensus group was to supplement for the hard technical evidence provided in the Delphi and Single expert approaches. Both methods were used in exploiting the un-quantified characteristics of human technical system to numerical data suitable for practical problem solving. Combining expert elicitations for best results have been dealt with in various publications (Taylor, 1997; Menezes, 2000).

6.2 Aggregated Results

To provide useful insight and establish a reasonable measure of accuracy, the results obtained were analysed based on the following deductions:

1. The pattern of data obtained from the elicitation is non-parametric therefore; beta PERT distribution was used to obtain the mean values. The fitness of beta PERT distribution to expert's score against other techniques has been

highlighted in Chapter 4. When a range of estimates are generated through expert elicitation, any of the probability distributions can be used as a tool to model results. However, the uniform distribution is limited to minimum and maximum values. Whereas, the triangle distribution uses most likely estimates in addition to minimum and maximum but is biased towards the most likely value (David, 2000)

2. Beta distribution is widely used in Bayesian statistics for estimation of prior and posterior subjective probabilities. Like the triangle distribution, beta- PERT uses most likely value over minimum, maximum but designed to generate a smooth curve distribution which is more realistic, and eliminate biasness.

3. By using the beta-PERT, the most likely values chosen are the values with highest cumulative frequencies. The minimum and maximum values were chosen from the results at shown in Table 5:6 in Chapter 5. The Beta distribution with parameters β_1 and β_2 has the following properties:

Format: Beta (β_1, β_2) with Probability density function given as:

$$f(\alpha)= \frac{\alpha^{(\beta 1)-1}}{\int_0^1 t^{\alpha 1-1}\,(1-t)^{\alpha 2-1} dt}(1-\alpha)^{\alpha 2-1} \tag{6:1}$$

Parameter restrictions; [$\beta_{1>}0$; $\beta_{2>}0$]

Domain [$0 \leq \alpha \leq 1$]

4. The Beta PERT has four parameter distributions which can enable modelling of experts' opinion within a limited error (David, 1997). The mean value is given as:

Mean= (min + 4*most likely + max)/6

$$\overline{\alpha} = \frac{(\alpha\text{min} + 4{*}\hat{}\alpha \ + \alpha\text{max})}{6} \qquad (6:2)$$

$\overline{\alpha}$ is the mean value, αmin and αmax are the minimum and maximum values respectively. In the analysis it was assumed that the score with highest cumulative frequency is the most likely value. This assumption is in agreement with the classical statistical inference of frequentist approach (Bedford, and Cooke, 2001).

6.2.1.1 ***Example:***

Consider for instance, Training from Delphi score in Table 5:1:

The Mean Likely Estimate (MLE) is = 80.5 (has the highest frequency of score = 5)

Let ^α = MLE = 80.5

(αmin, αmax) = (60.5, 95)

Applying equation (6:2);

$\overline{\alpha d}$ = (60.5 + 4 x 80.5 + 95)/6

($\overline{\alpha d}$) = 79.58

$\overline{\alpha d}$ = the mean value for Delphi scores, and ($\overline{\alpha s}$) the mean value for single expert scores

The mean values for single experts scores ($\overline{\alpha s}$) were also calculated in a similar manner.

5. Scores were combined to form weights which are then converted to probabilities by normalising. For instance;

Consider events 1,2…..,q ; representing the HEBC with probability vectors:

$Px_i = Px_1, Px_2 \ldots Px_9$ of some partition of the set of G of some possible worlds. If we assign $w_1 \ldots\ldots w_n$ to be absolute values (non-negative) that sum to unity;

For any real number r-norm; Weighted mean:

$$Xr(i) = \{\sum_{k=1}^{n} wiP_{ij}^{r}\}^{1/r} \qquad (6:3)$$

r-norm Probability:

$$Pr(i) = \frac{Mr(i)}{\sum_{q=1}^{n} Mr(q)} \qquad (6:4)$$

Pr(*i*) is a probability vector, and the normalising term:

$\sum_{q=1}^{n} Mr(q) = 1$ (sums up the probability to unity).

Mr(i) is the weighted arithmetic mean for each of the elicitation results for HEBC (q=1,2……n-1,n): P_d and P_s represent the probabilities obtained by weighting and normalising Delphi and Single expert impact factors respectively.

6. The final result shown in Table 6-1. The result was obtained by pooling expert's assessments, in the sense of linear pooling to form what is known as the *Decision Maker* (DM). The DM probabilities were computed by taking the normalised geometrical means of Delphi and single experts probabilities (Cooke 1991). This is provided by using the following model;

$$DM = \frac{1}{1+ (p_d p_s)^{-1/2} * [(1-p_d)(1-p_s)]^{1/2}}. \qquad (6:5)$$

P_d and P_s are the Delphi and single expert's probabilities respectively.

Therefore, the *Decision Maker* (DM) probabilities were calculated using equation (5:5).

The HEBC are represented by indexes X_1 through to X_9 in order of priority (influence on human performance) with X_1 as the most important human enhancing factor in operations. The categorisation is as follows:

1) Conditions X_1 to X_7 - These are enhancing factors on human performance

2) Conditions X_8 and X_9 – These are the operational *constrains* in human system interface in other words, *Impedance.*

Table 6-1 - HEBC Decision Maker (DM) Probabilities for Maritime Operations

Human Entropy Boundary Conditions (HEBC)		Delphi		Single Expert		DM-Probability
Index		$\overline{\alpha d}$	P_d	$\overline{\alpha s}$	P_s	DM
X_1	Quality of Crew	87.5	0.13	89.25	0.1375	0.13370554
X_2	Training	85.25	0.126	77.17	0.1189	0.12240571
X_3	Procedure	82.5	0.122	77.17	0.1189	0.12044139
X_4	Logistics	80.5	0.119	76.25	0.1175	0.11824794
X_5	Supervision	75	0.111	77.17	0.1189	0.11489093
X_6	Welfare	72.5	0.107	60.5	0.0932	0.09988833
X_7	Communication	67.5	0.10	77.17	0.1189	0.10909133

X_8	Stress	67.5	0.10	63.83	0.0983	0.09914676
X_9	Environment	57.5	0.085	50.5	0.0778	0.08132741
		675.75		649.01		
$\sum_{i=1}^{i} PX$			1.000		0.9999	0.9991453

6.3 Human Failure Modes

When reviewing and improving the existing approaches, the subject matter experts relied on accident databases for guidance regarding failure patterns. Following the outcome of the elicitation, the patterns of human contributions to failure were uncovered in *tripartite* mode, this was provided in Chapter 4. The Consensus group deliberated and summarised the results as shown in Table 6-2.

Table 6-2- Generic Accident Type per Cause of Human Factor

Serial	Incident	Impact Factors by Human Failure mode derived by SME		
		Cognitive error	Negligence	Breach
1	Fire	3	12	4
2	Explosion	6	4	0
3	Capsize	1	1	0
4	Collision/Contact	2	9	3

5	Stranding	1	7	1
6	Grounding	4	7	3
7	Flooding	2	8	2
8	Leak/Spill	1	8	3
∑ Sum of Failure Modes		20	56	16

For each accident category, the human failure mode impact factor was identified following the study conducted on the frequency of accident per generic root cause as was presented in Chapter 4.

Therefore, applying the classical model concept, from equations (5:4) above:

$$\text{r-norm Probability} = \Pr(i) = \frac{Mr(i)}{\sum_{q=1}^{n} Mr(q)} \qquad (5:6)$$

Therefore, applying this model;

Probability for failure due to Cognitive error $= P_c = 0.217$

Probability for failure due to Negligence $= P_n = 0.60$

Probability for failure due to Breach $= P_b = 0.170$

The human contribution to maritime accidents can be quantitatively categorised as shown in Figure 6:1 in percentages.

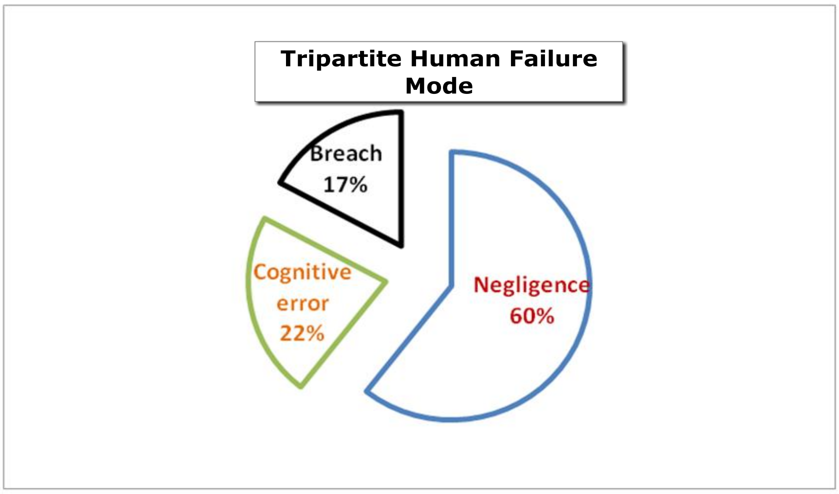


Figure 6:1 – Distribution of Human Failure Modes in Maritime Accidents

In this milestone finding, the Cognitive error, which has been the focus of much research in HRA, represents barely 22% of the failures. This result creates a new corridor which could be used to advance the scope of HRA. This new venture can provide a practical performance prediction tool in line with the widely acclaimed new safety regime for operational resiliency: Resilience engineering and Efficiency Thoroughness Trade-Off (ETTO) (Hollnagel, 2006). The *tripartite* failure mode covers all forms of human-system interactions in operations vis-à-vis human instinct to make adjustments, parameter manipulation, risk taking, corner cutting, management interferences and profiteering attempts etc. These endeavours are workplace rationalities and operators utilises knowledge and skill to maintain system persistence according to the situation (Allen, 1982). Therefore, by this information it is clear that the word error is misleading since in the real world, local rationality in operations requires a particular way of thinking to cope with prevailing or emerging exigencies. Since humans are logical actors, deliberate additions and subtractions may be conceded irrespective of perceived risks to satisfy employers' demand for efficiency and productivity. In many instances' interest undermines the principle of safety and capability. Negligence manifests itself in the form of risk taking which creates opportunities for failure. In negligence, existence of a problem may be taken for granted or simplified by creating an impression of manageability, and in some cases expert solutions may exist but logistics may not be available.

Bounded rationalities are particular acts of violations which involve unprecedented additions, subtractions, alterations and normalisation. Reason classified volitional issues into Routine, Optimising and Necessary (Reason, 1997). Similarly, various theories on accidents causations have been advanced by different scholars that indicated human failure modes for instance, the Heinrich's Domino theory which was discussed in Chapter 4 uncovered causes of failure as follows:

1) Accidents caused by unsafe acts = 88%
2) Accidents caused by unsafe conditions = 10%
3) Contingent accidents (unavoidable) = 2%

6.4 The Performance Shaping Factors (PSFs)

The Health and Safety Executive (HSE) defines human factors as '*the environmental, organisational and job factors, and human and individual characteristics which influence behaviour at work*' (HSE 2007).

The PSF are used to model human behaviour as the causes or contributors to abnormal behaviour or deviation from safe practices (Kim 2003).

These PSFs take different nomenclature in accordance to the method of modelling; examples include are but not limited to:

1) Performance Shaping Factors (PSF)

2) Performance Influencing Factors (PIF)

3) Performance Affecting Factors (PAF)

4) Error Producing Conditions or Factors (EPC/EPF)

5) Common Performance Conditions (CPC)

6) Pre-condition for Unsafe acts (PCUA)

The evidence and causes of human error are generally qualitative, and according to the general principle of causality, any manifestation, including the failure to do something or the omission of an action, must have a cause (Hollnagel, 2000; Wiegmann 2001). Safety measures are aimed at achieving the desired safety and the quantification must provide result oriented guidelines. HRA models should be iteratively flexible in context to accommodate proactive and reactive circumstances. This will enable the exploration of what is controllable and what is not. Rigorous analysis and assessment of human factors is necessary so that effective recommendations can be made and acted upon in order to control accidents; these include human aspects which can increase the risk of such incidents in the first place (behavioural differences, emotion, perception, personality, decision-making, cognition, fatigue, stress, etc.). ‘

Since no PSFs can satisfy all applications, the challenge in a HRA is how to develop a high-level model that is industry specific in requirement. The model must be able to accommodate specific changes in PSFs for modelling of risk under different scenarios. More robust searches on the causal factors of human contribution to failure is imperative because most, most models do not include rare conditions or appreciate the need for rationalities during operations. The consensus groups aggregated the scores using the Decision Makers Probability equation 5.5 shown above as follows:

$$\text{DM}= \frac{1}{1+ (\, p_d p_s)^{-1/2} * [(\, 1-p_d)(1-\, p_s)]^{1/2}}\,. \qquad (6.5)$$

The taxonomies of Performance Shaping Factor (PSF) are so developed as to be suitable for a specific purpose and application. The set of PSFs considered for HRA is slightly different and entirely depends on the quantification procedure designed by the analyst. The variability may pose some important problems such as:

1) Trust – The values for the Human Error Probabilities (HEP) calculated between different HRA methods that used different sets of PSFs may differ significantly. This clearly shows that it will be meaningless to compare HRA results derived from different models.

2) Scope – The scope of coverage for PSF in some HRA methods is limited compared to others. Models with limited coverage of PSFs are likely to omit some strategic error reduction measures. The use of limited PSFs may underestimate the scope or extent of human error which may consequently result in assessing safety lower than reality.

3) Characterisation – The characterisation of PSFs is aimed at providing details of the utilities involved in the definition of PSF. The characterisation differs in the taxonomy of the PSFs from one HRA model to the other, which also yields different human error results.

Performance Shaping Factors (PSF) are essential in determining and understanding the root causes and opportunities for manifestation of failure. Different practitioners have differing views and perceptions on the scope and context of the PSF, which also gave rise to different taxonomies. However, too many of these factors are likely to create uncertainty and too few of the PSFs will create misleading results.

6.5 Concluding Remarks

This Chapter discussed the qualitative and quantitative analysis of data mining results and the appropriate probability theories used to analyse the data. The taxonomies of Performance Shaping Factors (PSFs) were so developed as to be suitable for a specific purpose and application. As no PSF can satisfy all applications; the challenge in HRA is how to develop a high-level model with requisite PSFs that is industry specific. In maritime operations, compliances to safety rules are not feasible seemingly due to isolation, complex systems and aggressive environment in which the crew and system operate. Results obtained from the data sources and experts elicitation indicated that 60% of all maritime accidents are due to negligence and 17% due to breach, while the widely acclaimed cognitive error is about 22% in part. The tripartite failure mode is a pointer to human entropy meaning; disorderliness. The impression; human error is misleading because human contribution to failures is as a result of the combination of cognitive error and unavoidable volitional acts. The word entropy is a doctrine of degeneration; widely used in science and engineering to quantify the degree of uncertainty or disorderliness. The volitional acts are mainly due to efficiency thoroughness trade-offs in scarcity of logistics, profiteering and other forms of corner cutting. That’s not withstanding, in the apex of failure or accident crew will strive by all means to sustain operability and recover from failure. And in so doing, all acts of violation are genuinely justifiable and all forms of error may consequently manifests.

Nine human entropy boundary conditions were identified as the generic performance shaping factors in man-machine interface and are called Human Entropy Boundary Conditions (HEBCs). The HEBCs are; Crew Quality, Training, Procedure, Logistics, Supervision, Welfare, Communication, Stress and Environment. The most important boundary condition is crew quality with success probability **0.13371**, followed by Training with **0.1224**. Stress and the Environment condition were assumed to be constrains to successful operations in maritime environment, they are therefore called retarding forces or operational constrains.

The *raison d'être* for the tripartite failure mode is to supplement for operational constrains and to some extent for economic benefit. Because, the causal factors and operational boundary conditions of accidents are inexhaustible, inferences, using hypothesised variable construct were used to illuminate HEBCs in context. The HyCs variables are derivatives of HEBCs which are used to define what compliance to safety should be and what deviation to safe operability might be. By this design, possibilities of error and potential opportunities or holes for volitional acts can be predicted. Details on the probabilistic analyses of this concept are provided in subsequent Chapters.

CHAPTER 7. The Human Entropy - Proposed Approach to Human Reliability Analysis

7.1 General Remarks

The aim of this study is to develop a multi-utility human reliability assessment tool, specifically for maritime applications. So far, a number of issues have been discussed on HRA and its practices. The paradigm of human factors is wide and complex; and it involves individual social and cultural psychology, system hardware, management and environmental behaviours. The challenges and constraints facing human reliability analyses are:

1) Lack of representative data on human factors. This is because each individual is unique, and poses different capabilities, social and cultural status

2) Lack of validity of human error probabilities. This is because validation is data-fixated and compliance to safety is relative

3) Humans are a fallible machine and to “err” is human. In this case, the challenge is to develop a mechanism that can predict error potentials and limit the failure.

4) Human performance is a function of PSFs. Only accurate representation and application of boundary conditions will facilitate reduction in failures.

5) Efficiency Thoroughness ‘Trade-Offs (ETTO) in maritime operations are common and seemingly inevitable. Therefore, crew capability is a prerequisite for resiliency. HRA models must have a quantitative structure that can measure or predict crew capability.

The elicitation results were quite challenging because interesting milestone discoveries were made. Knowledge on personnel/crew capabilities, management behaviour and environmental characteristics enables human entropy to be predicted in a range of circumstances.

7.2 Evolution of Human Entropy (HENT)

Entropy is a popular word which is commonly used in the science of thermodynamics, statistical mechanics, communication etc. It is meant to represent missing links or disorganisation in various fields of applications as follows:

7.2.1.1 *Definition of Entropy*

1) **World English Dictionary** – Disorderliness, lack of pattern or organisation.
2) **Cultural Dictionary** – Measure of disorderliness of any system; Inevitable and steady deterioration of a system or society
3) **Thermodynamics Entropy** – Is the unavailable energy that is required for work in a thermodynamic process. Entropy is a function of Temperature, Pressure or combination.
4) **Information Entropy** – A measure of information in a transmitted message.
5) **Statistical Mechanics Entropy** – Entropy is was derived from the study of thermodynamic process and given as:

$$S = K \ln \Phi$$

Where; S is the entropy (measure of disorder of a system) ; K is Boltzmann constant and Φ is the number of microstates or possible ways that a given condition can occur.

Therefore by analogy, Human Entropy (HENT) will henceforth be applied in this study to represent the measure of disorderliness due to human actions. The word "human error" is misleading when applied to human reliability especially in maritime operations because the scope of human contributions to failure is limited. Entropy is widely used in science and engineering to quantify the degree of uncertainty or disorderliness in a system, it is a doctrine of degeneration. In thermodynamics, entropy is a quantity representing the amount of energy in a system that is no longer available for doing mechanical work. In communication theory, "*entropy*" is a numerical measure of the uncertainty of an action. So when applied to human reliability studies, human entropy is a measure of human contribution to failure due to disorderliness (error, negligence and breach). A summary of the doctrine of Entropy is shown in Figure 7:1. In HRA human entropy is all-encompassing and a detour to the concept of human error. In maritime operations, observances of safety rules are not always feasible and so predictability of crew requires advanced models. This situation, prevalent in the maritime industry, can be attributed to situational changes while in an isolated environment and disposure to complex technical systems. Situational variations can be influenced by rough weather conditions, work complexities, exhausted logistics, increasing work stress etc. Although, resources may be committed on personnel training and supervision, *latent factors* and *microstates* (number of possible ways a given condition can occur) may influence disorderliness.

The development of HENT gave the datum line for deeper investigation into what constitutes the generic human performance shaping factors. The results sparked off a new initiative to widen the scope of HRA with practically-oriented performance prediction tools which will also be in line with the new safety initiative in resiliency engineering and ETTO (Hollnagel, 2006). Interestingly, nine performance shaping factors were identified for maritime operations and will be discussed later. Invariably, human entropy is a function of space and time. The progression of human action in operations is viewed within an allotted space and time to accomplish a task. At sea, crew members must strive in all respects to maintain system continuation with vigour and act in a timely manner according to schedule. In so doing, the crew encounters many challenges and some of the challenges may require discretionary action; this trend is reflected in Figure 7:2. At the outset of maritime operation, it is only natural as a routine for all crew to follow procedures and monitor the system's behaviour under normal conditions. If the crew notices any deviation from normality, the operator must take action either to report or adjust the system. The Crew may also take both actions simultaneously. While it is possible for the crew to succeed, it is also possible to err or introduce latent error (errors which may not be noticed at the instance they were introduced). If the system works fine otherwise, failure may be accompanied by accident.

However, if the action taken by the operator becomes successful, the crew must carry out test and safety checks in order to minimise short- and long-term effects. Thereafter, the incident must be reported and documented. As a consequence, more vigilance and communication is required because the ship is a moving platform on board which different departments are interacting continuously.

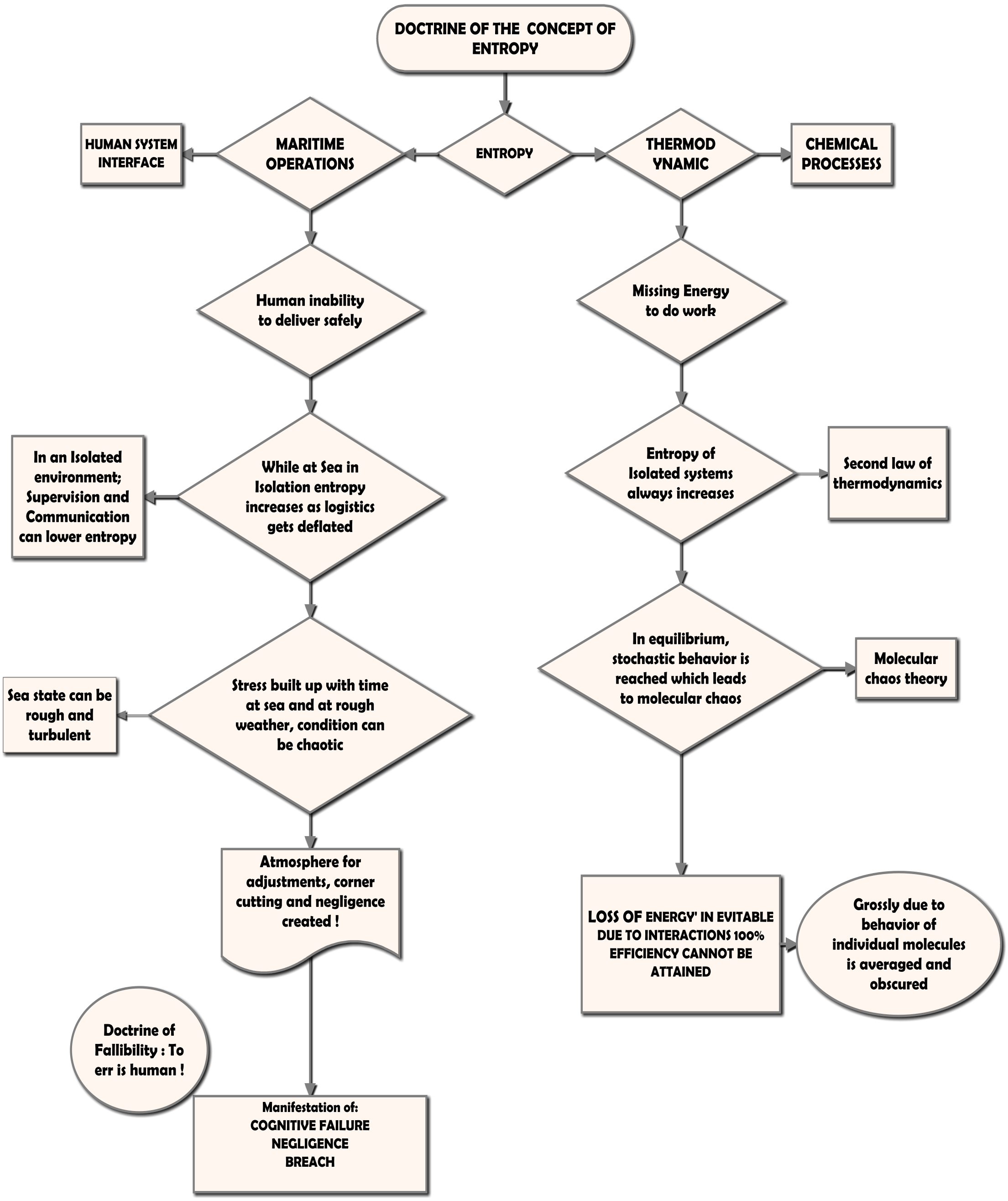


Figure 7:1- Doctrines Concept of Entropy

As the system is impaired, the mission can only be accomplished by removing the causes of instability, perhaps by reducing the expectations of the captain or the management by defining lesser but more achievable goals.

Things may become more complicated if the captain or management become hostile when crew cannot overcome or manage defects. When a system is operating under certain adjustments or modification, the mission is delayed and the system becomes susceptible to all manner of volitional acts such as; negligence in communication, documentation, monitoring, and so on and so forth. Consequently, as this practice of adjustment continues, the system's integrity becomes prejudiced. Entropy or disorganisation will be imminent and will be accompanied by increased workload, distractions in lookouts, and disorganised watch plans, thus drifting from safety.

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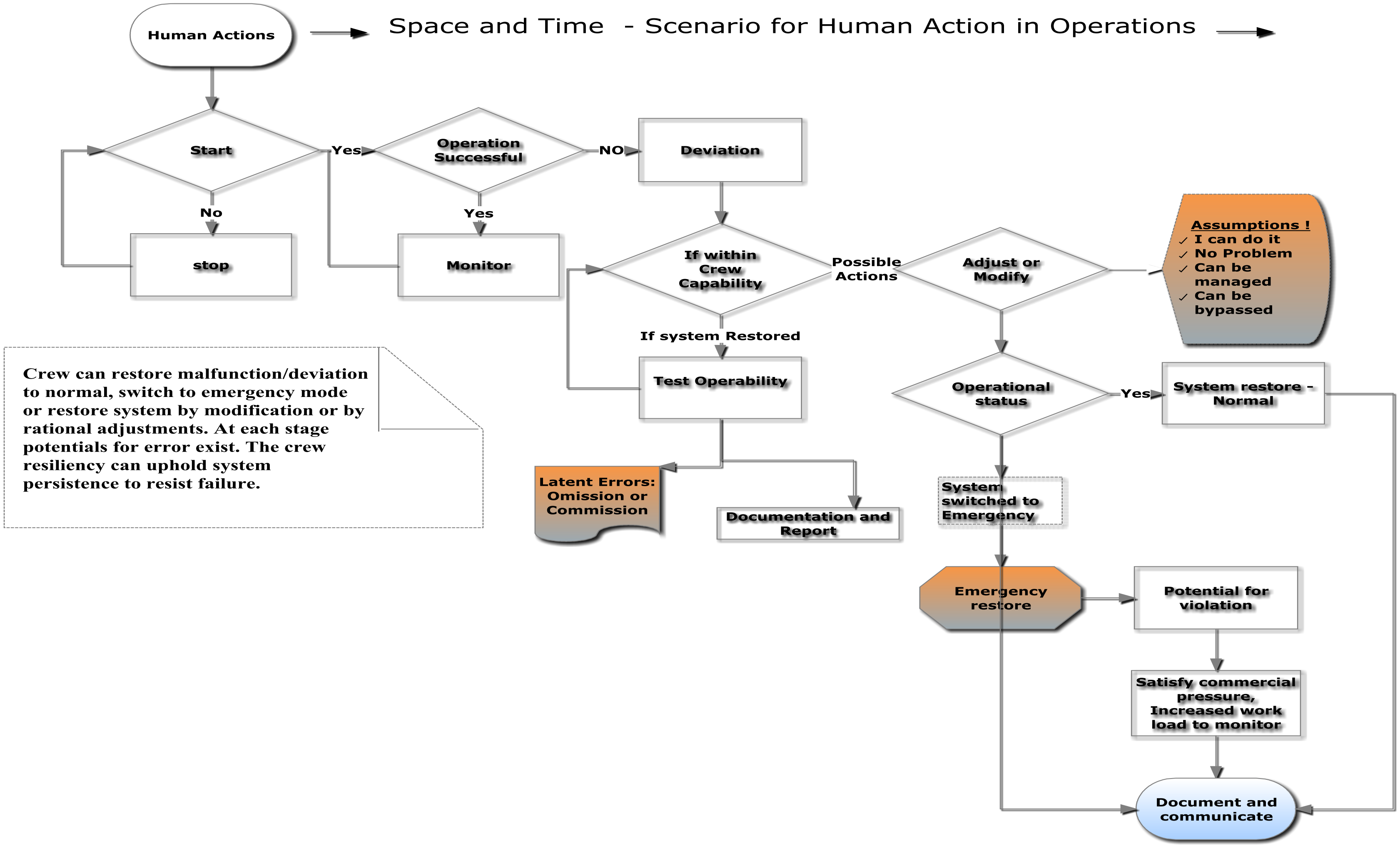

Crew can restore malfunction/deviation to normal, switch to emergency mode or restore system by modification or by rational adjustments. At each stage potentials for error exist. The crew resiliency can uphold system persistence to resist failure.

Figure 7:2 – Time domain human actions in Maritime operations

7.3 Cognitive Error (Ec)

Cognitive error is a result of deviation in mental judgment which may lead to erroneous actions such as lapses of memory, fumbles and mistakes etc. Cognitive error is however a result of the "*doctrine of fallibilism*" (Cooke and Elizabeth 2003). Most cognitive task analysis models make use of models of mental processing and in this case, goals are achieved by solving sub-goals iteratively in a divide-and-conquer fashion. Cognitive error modelling concepts are well described in CREAM and Goals, Operators, Methods and Selection rules (GOMS) (Card and Moran 1983). In HRA, representing human cognitive phenomenon quantitatively is ambiguous and has not been successful (Barnard P 1987). For instance, there are no available tools that could be used to capture/measure skills, rule or Knowledge-base errors and unless each individual crew is assessed in terms of his/her knowledge, experience and capabilities, any attempt to predict cognitive errors based on task or data will produce misleading result.

HENT model has developed scaling that could measure each individuals' characteristics which may be susceptible to cognitive errors under the Crew Quality Audit (CQA). A conceptual framework for HRA using the HENT model for predicting and mitigating cognitive based errors is shown in Figure 7:3.

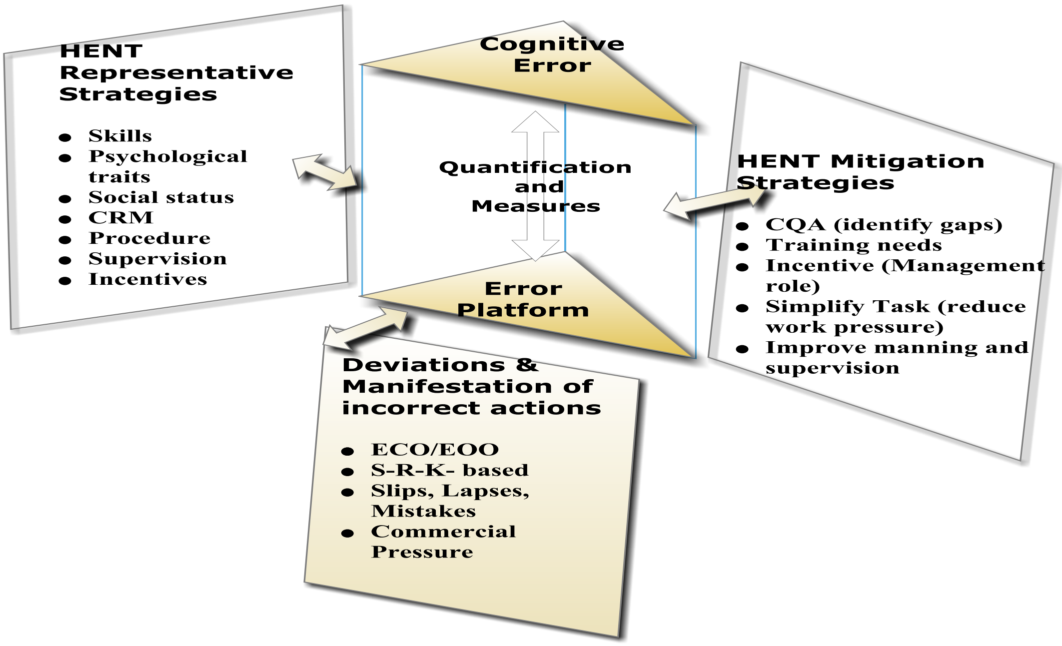

Figure 7:3 - Cognitive Error Performance Measurement and Mitigation Strategies

7.4 Negligence (en)

Negligence is a result of imprudent human behaviour, lack of concern, or failure to exercise a degree of care which may result in unintended accidents. The intension is not to harm or permit accident, but failure may happen due to lack of good appreciation of the level and impacts of risk. Negligence may be a result of; tiredness, low morale, carelessness or self interest etc. Negligence is not only a property of the operator, but also a factor in management for instance, in refusing to take action on reported hazards or over reliance of crew to accomplish goal in the required manner despite boredom, stress etc. According to risk homeostasis theory, risk taking should be seen as human instinct and every individual has a tendency to take risks in his own way (Wilde 2001). The HENT model has taken into account the indices of negligence (extraneous acts) and mitigation measures by utilising the HyCs variables. The counter and predicting variables are: individual hazard perception and realisation of failure, crew health state, psychological traits, sociability, welfare, task complexities etc. A scenario for the driving and associated restraining forces on negligence is depicted in Figure 7:4.

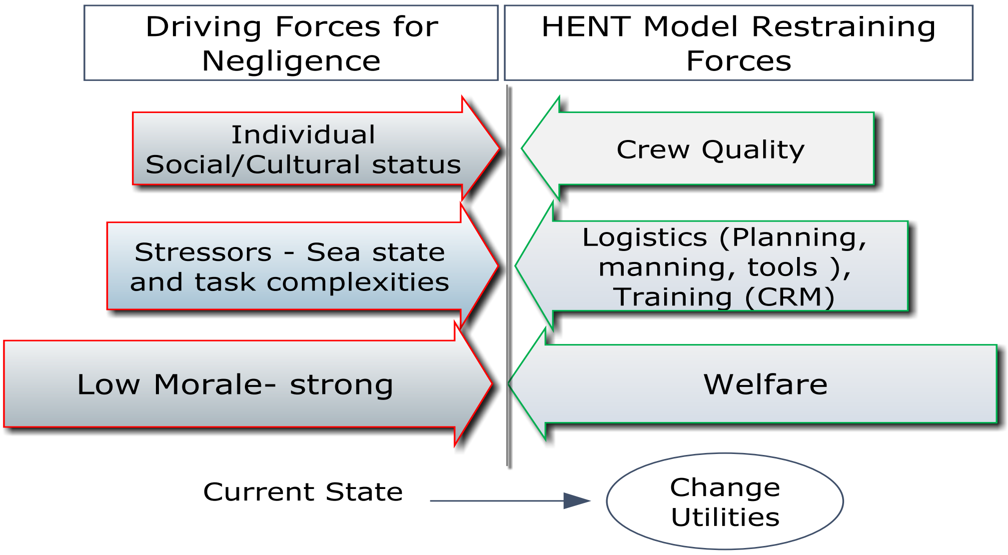

Figure 7:4 - Driving Forces for Negligence and Restraining Forces

7.5 Breach (e_b).

Breach or bounded rationality means act(s) in disregard of rules, or failure to perform an obligation consciously, with or without intention to harm. In reliability analysis we rule out acts of sabotage and therefore breach may be due to compromise in thoroughness for efficiency or due to individuals' ego in which case the crew may bypass procedure because of familiarity with the system. Latent factors also play a vital role in manifestation of breach, such as; welfare, organisational politics, ego, mental state, morale, social and cultural psychology etc. Breach may also be influenced by scarce logistics which, may lead to unprecedented Alterations and Additions (A's & A's). The danger in A's & A's is that when the original design is breached, latent errors may be introduced. It is called latent error in the event that the action leads to failure due to an unnoticed gap (*pathogens*) created in system the safety. If however, the A's & A's did not cause immediate failure, the change is normalised. If such changes are not documented or communicated around crew, it is possible that one day a procedure compliant crew may reverse the adaptation. The reversal may trigger immediate failure because the original defect has not been resolved. The scenarios surrounding the driving forces around breach are depicted in Figure 7:5.

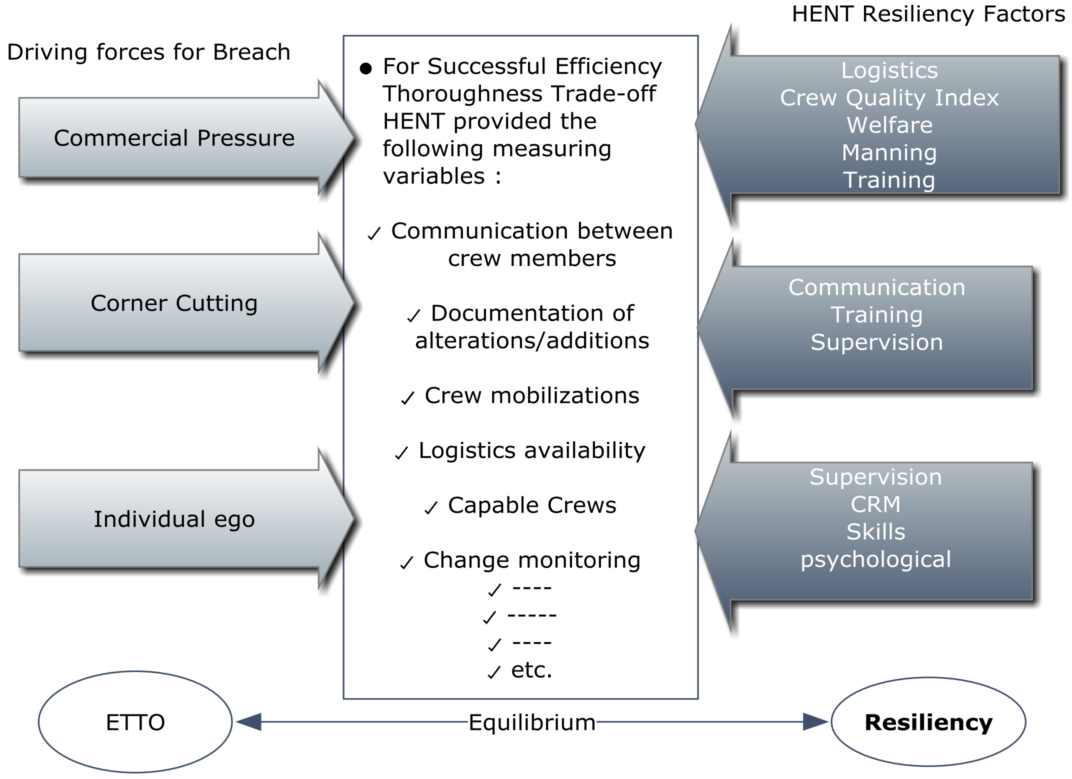

Figure 7:5 - Breach Force Field Analyses

The HENT model takes on board all forms of human-system interactions in operations vis-à-vis human intuition to make adjustments e.g., enhance speed, risk taking, corner cutting, management dictatorship and pursuit for profit etc. These endeavours are work place rationalities in which crew use their knowledge to maintain system persistence according to the situation (Allen 1982). Each system has its operational manuals: for normal and emergency operations. There are however limits to technical systems that could prompt the operator or refute equipments inoperability in the event of unprecedented malfunction. The HENT modelling technique hypothetically, develop mechanisms that could at least predict and indicate conditions requiring attention for crew to recover from abnormal circumstances.

7.6 Crew Resiliency

Work regulations and procedures are not as much of effective as they are normally believed to be. Technically, it has been uncovered that most of the failures are due to human element, this is not because rules and procedures are not specified but because of the way in which humans actually behave. Since bounded rationality and extraneous acts are inevitable in operations, crew must be relied upon to handle all forms of unanticipated perturbations subject to competence to prevent undesirable event. This is especially, as operational condition necessitate Efficiency Thoroughness Trade-Off (ETTO). Resilience is about bouncing back from hard conditions or ability to endure difficult circumstances and to stay within safe envelope to avoid accident or failure. To be resilient, management and crew must develop flexibility to deal with unexpected and unplanned situations and respond sharply to events diligently to sustain system persistence.

Training is important but so too in what is going on in the case of logistics. Provision of logistics and welfare, for example can make available opportunities to develop operational resiliency. Resilience functions with protective factors that are associated with crew morale. Therefore, the foremost resilience factor is the crew quality which is defined in the HENT concept by crew capability audit utilities. Several features can be attributed to resiliencies which were advanced by scholars (Gilligan, 1997). Some of the fundamentals of individual resiliency are:

1. A safe and sound foundation where personnel feel a sense of belonging and job security
2. Noble self esteem (having an internal perception of worthiness and competency)
3. Sense of mastery and control (self efficacy) and good appreciation of personal strength and limitations.

Therefore, in the wake of human disorderliness (entropy) resiliency must evolve to safeguard against undesirable events.

7.7 Human Entropy Boundary Conditions

The PSFs are used to model human behaviour as the causes to abnormal behaviour or deviations from safe practices. Different practitioners in HRA have different ways of assessing human influencing factors since no universally agreed classification and taxonomies have been made. Figure 7:6 provides the general overview of the research findings on the HEBCs. The numbers in the Figure allocated to each boundary condition indicate the relative probabilities for maximum reliability in operations. These values were computed and discussed in Chapter 5, at Table 5:1. The left hand side of Figure 7:6 shows the retarding HEBCs also called the *stressors* whereas, the enhancing HEBCs are shown at the centre. The HEBCs were decomposed into HyCs with 137 degree of freedom as shown in the logic worksheet. Crew quality has the highest positive impact probability in human performance, followed by Training. There are two conditions that impact negatively on crew performance; work stress and sea environment. The work stress and sea environment are the main operational constraints.

Progress in human entropy investigation led to the evolution of Human Entropy Boundary Conditions (HEBC) as new specific performance shaping factors. The evolution of human entropy boundary conditions allow inclusion of local rationality variables that may have been implicated due to operational exigencies. The contextual meaning of the 9 HEBCs are provided in Appendix 5-4 whilst, Table 7-1 shows the detailed breakdown for Logistic as an example.

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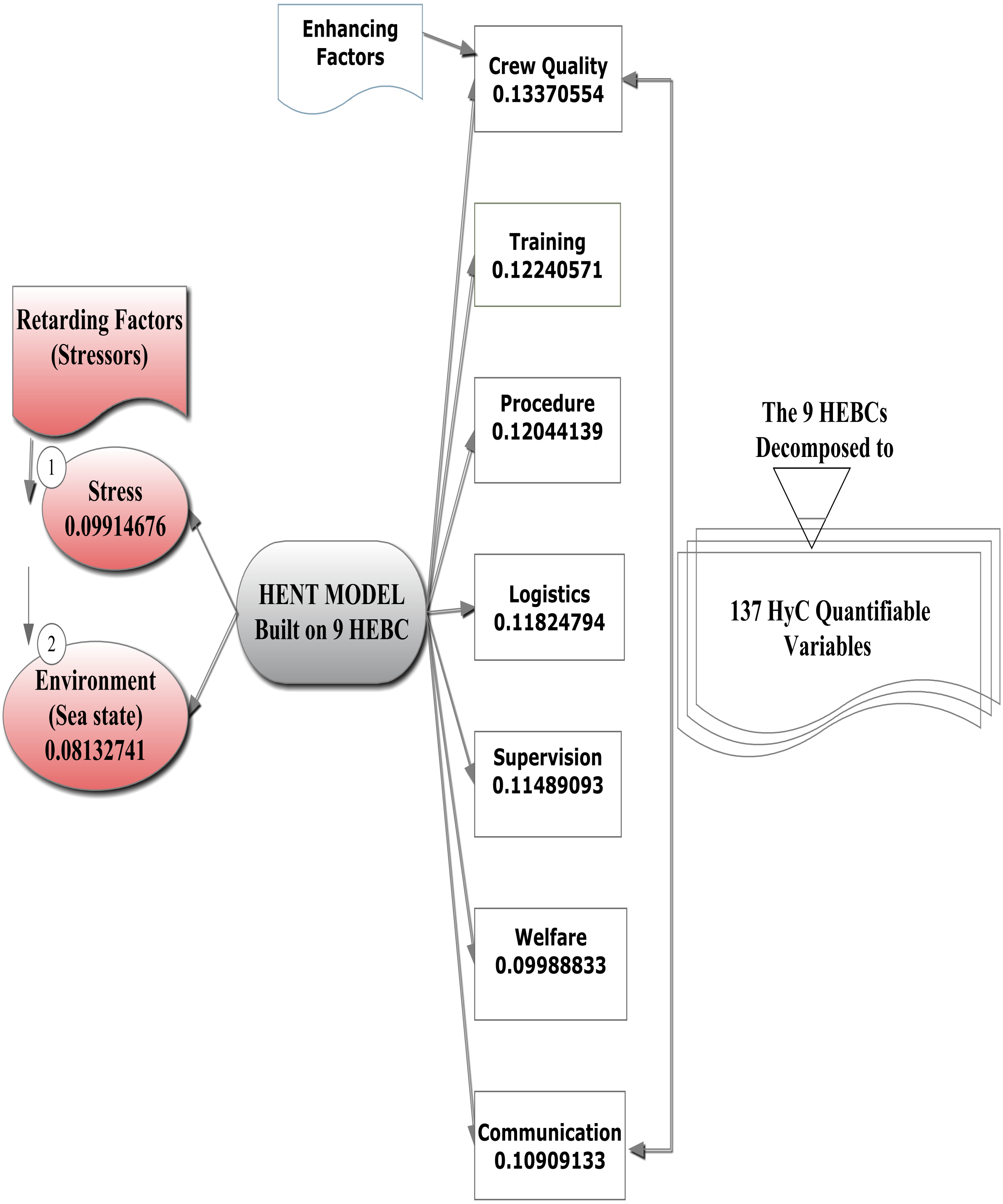


Figure 7:6 – Generic HEBC with Impact Probability Factors

Table 7-1 – Contextual Breakdown of HEBCs into HyCs Variables for Logistics

HEBC	Latent Variables	Hypothetical constructs (abstract concept)	Reliability status	Definitions and remarks
Logistics				
	Maintenance.			In house (operator maintenance scheme) improves crew knowledge, belonging and sense of duty.
		Repair		A situation in which crew are directly involve in maintenance, repair and calibration
		Servicing		When crew are involved in basic servicing, or operational tests only
		Contract/external servicing		When both repair and servicing works are contracted out
	Spares/tools			Availability of spares and tools for onboard or offshore repairs

		Spares/tools available onboard		When complete inventory of necessary spares and essential tools are borne on board e.g. servicing calibration , repair of essential defects and damage control/fire fighting.(DC/FF)
		Spares/tools by request		Spares and tools are supplied based on request.
		Spares/tools not adequate	-ve	When spares and tools are not available for servicing equipments. Crew struggle to manage
	Time/planning			Management/organisational ability to plan operations well ahead of time. Resources made available, system/ equipment put in operational state and personnel adequately prepared. This will eliminate last minute rush and reduce commercial pressure
		Very good scheduling		Resources adequate, material/ship/system and personnel well prepared and all departmental logistics supply on time.
		Fair scheduling	+ve	Logistics and preparation of system carried out

				at last minute
		Poor planning and scheduling	-ve	Commercial pressure heavy and to adequate time to meet up with logistics requirement as demanded by departmental heads.
	Manning			
		Adequate		When normal duty/watch periods at sea are 4 hrs on and 8 hrs off cycle is operated. This is the Navy standard.
		Average		When at least, 6 hrs on and 6 hrs off cycle is operated
		Below average	-ve	When 6 hrs on and 4 hrs off-duty schedule is operated or 8hrs –on /6hrs-off.
	Resource availability			
		Available		Adequate provision of all financial and material requirement for operation as provided requested

				by heads of departments
		Partially available		Situation when resources are partially made available and without reserve for emergency
		Poor	-ve	When operational resources (allocation) are denied or sub-standard items provided. Company reliance's on incrementalism is encouraged – additions and alterations becomes normalised without due diligence.
	Age of equipment			
		1 to 5 yrs		When the equipment is new and not more than five years in service from date of commission
		6 to 10		
		11 to 15		
		16 to 20	-ve	Degraded reliability
		over 20	-ve	When the system/equipment is old – over 20 years in service reliability is highly reduced.

7.8 Merits of HEBC

Human Entropy Boundary Conditions (HEBCs) have varying applications in assessment of safety, accident root cause analysis, identification failure modes and in mitigation such as:

1. Identification of accidents and safety critical operations in the marine industry and the contributory factors. This can be realised by gathering and reviewing various data sources and research available on marine accidents and the underlying reasons.

2. Identification and quantification of the practice of taking *shortcuts* in ship/marine operations. The HEBC will facilitate identification of all the circumstances which give room to the practice of taking shortcuts in relation to the crews' job tasks can be realised.

3. Establishing relations between accidents and 'underlying reasons', for the practice of shortcuts to identify potential human errors and the potential positive and negative outcomes of the shortcuts.

4. Identification of and quantification of functional demands of maritime operations in normal and emergency situations.

5. Identification of crew limitations and capabilities including the crew profile with relations to rank and ratings can be realised in a number of ways by utilising the HEBCS e.g. Determine (Mapping) the functional needs of the crew during the normal and emergency situations.

6. Crew functional needs for safe shipping operations ,

The nine HEBCs were also compared against fourteen other HRA modelling techniques and as shown in Appendix 7-1, and it was observed that there is very good agreement. The Common Performance Conditions (CPC) in Cognitive Reliability and Error Analysis Method (CREAM) which has higher contextual detail, were also compared with HEBCs as shown in Table 7-2.

Table 7-2 - Comparative Analysis between CREAM and HEBC

Serial	**CPCs (For CREAM)**	**HEBCs**	**Remarks**
1	Adequacy of Organisation	Welfare/Logistics	No clear definition is given in the CPC taxonomy whereas in the HEBCs the breakdown is very clear
2	Working Conditions	Environment	Very similar
3	Adequacy of MMI and Operational Support	Logistics/Supervision	HEBCs utilities are more specified
4	Availability of Procedure and Plans	Procedure	Procedure has a wide coverage in HRA, but the definition of plans is not universal rather differ from one industry to another.
5	Number of Simultaneous Goals	Stress	The number of simultaneous goals measures only stress.
6	Available Time	Logistics	HENT model Time under

		(scheduling)	planning in logistics
7	Time of Day	Stress (circadian rhythms)	In HENT, Time of the day is also a function of manning which was also treated under logistics (manning)
8	Adequacy of Training and Experience	Training/CQA (Skills)	CREAM fail to define what is adequate training
9	Quality of Crew Collaboration	Crew Quality Audit/Supervision	In CREAM collaboration is the quality or degree to which the crew members collaborate with one another. Whereas CQA directly assesses individual capabilities such as skills, physical and psychological sates. It also includes crew social and cultural status.
10	Communication Efficiency	Communication	

There are many factors that affect human performance and trigger accidents such as; pursuit for high profiteering, corner cutting, wrong diagnosis and habits, work load, morale etc. The qualitative and quantitative boundaries for safe performance have been exhumed in this study as; the Human entropy boundary conditions (HEBCs) Performance Shaping Factors. The HEBCs can be manipulated to exert control by changes to the work environment, procedure, provision of adequate tools, improving of crew quality to set up resilient personnel etc. Figure 7:6 display the summary of results for HEBC obtained from the previous Chapter and highlights the enhancing and retarding factors to human output in man-machine interface. The next stage is to provide an explication and praxes of the human entropy boundary conditions which have been a theme point in the application of performance shaping factors in any HRA. Therefore, the explication of the nine HEBCs is provided using hypothetical construct variables which are discussed in the succeeding chapter. The quantitative breakdown of the boundaries for safe performance will reveal vulnerability to decision makers and the axioms for safe operation can be fine tuned.

7.9 Hypothetical Construct Variables (HyCs)

The 9 Human Entropy Boundary Conditions (HEBCs) have been developed and each with its relative probability on how it impacts on human performance. The HEBC are the theoretical terms logically derived exclusively from specific data with probability that is permissible and sufficient. Given the HEBC data we cannot know how to quantify safety or measure the operational reliability without contextual details. The Hypothetical Constructs (HyCs) are inferred dynamic variables conceived to reveal good practices and operational weakness or constraints.

Predictability and attributes of hardware systems are known from historical data, whilst soft systems such as humans have differing values, personality, vested interest, views, morale etc, which makes predictability quite complex. Therefore, to make the HEBCs probability worthwhile and useful in the predictions, they need to be exploited in context with well defined rules and procedures to retain reliability and validity. This is very important and relevant to the concept for control and sampling, reducing biasness in blind usage of unitary value of any one of the nine HEBCs

7.10 The HyCs Probabilities – The Logic Worksheet

Hypothetical constructs are mediating variables which must be inferred from the HEBCs data sets for clarity and application. The mediating variables are links of chain of events that define each boundary condition and explore the contextual characterisation. These mediating variables are used to give meaning to the data sets for quantification and are called Hypothetical Construct (HyCs) variables (Kozak and Miller 1982). The choice of these variables depends, quite, on the inferential level and explanatory breath of the concept. The Decision Maker (DM) probabilities provide discrete dependent values for each HEBC utilities which were exclusively derived from data. Therefore, recognising the enormity of multi-systems, multi-dimensional assessment must be carried out to attain accuracy. The consensus group categorised the HyCs variables chronologically in order of priority on how the variables impact on operational safety. From the sequence of the arrangement, probabilities were allocated for the latent variables and the aggregate maximum values must sum up to the value of the main component.

Similarly, the sum of the values of all utilities in the main component must add up to the maximum relative probability of the HEBC. The HyCs variables were used as the logical thought process or abstract concepts which operationally define the entropy boundary conditions in context. The HyC variables are not exhaustive or directly observed, but rather inferred. Responses are not essentially, meant to correlate with each other, but must comply with hypothesised psychological process (Donchin, 1979). Using the HyC variables, the assessor can identify the risks around safe operational boundaries, and the utilities can be used to improve or decrease human reliability. A number of issues, which beclouded the human factors in the maritime industry, can be well represented. Details of the HyCs variables probabilities are shown in Table 7-3 in and it is called the Logic Worksheet for HENT Model. Each of the variables in HyCs, was allocated positive and negative probability signs. For example, consider the probability axioms for Logistic in Table 7-3:

Sum of all HyCs (under logistics) = Max Log

Maximum probability of impact for Logistics (Max Log) = 0.118248

The negative values signify holes (potential risks) in operations, while positive values increase operational reliability. Stress and Sea state or *stressors* and any other utility that is deemed constrain to safety are allocated negative probability values and are called the *impedance probability*. However, the axiomatic foundation which ensures probability law is preserved; meaning:

$\sum P(FX) = 1$

Therefore, irrespective of sign convention,

$\sum P(FX) = 1$ (Imposes restrictions)

$\sum P(Fx) \geq 0; \leq 1$

$P(X)$ is true for all X

$P: (-1) \leq P \leq 1$

Each of the utilities in HEBC can be treated as random functions (stochastic) since each is composed of dynamical set of random variables of HyCs. The variables can be treated as probability vectors which could enable positive and negative probability signs for

success probabilities and ***impedance probabilities*** and then normalised as idealised linear entities. The cumulative probability will then be determined linearly.

In the context of relativity format for reliability analyses, classical probability inequality can be defined as:

i. $P > 0$ (gain or success probability).

ii. $P = 0$ (indicate failure)

iii. $P< 0$ (consequence or *Impedance* probability)

iv. By linear combination ;$\sum P \geq 0; \leq 1$

The mean values of the HEBCs which are compared with one another are formed with the same weight The reliability associated with HENT must then be the sum (linear aggregate of *Gains and Loss Utilities).*

The impedance probabilities can only appear in the intermediary stage. It allows prudence in reasoning which will enable different cases to be accommodated within the axiom of causality. While in other risk and reliability assessments negative probabilities are used such as in quantum theory, finance and information theory, it is seemingly neglected in human reliability analyses even when the application involves technical systems. The concepts of loss function ‘regret’, in Bayesian statistics by logical inference is an indirect application of negative probability. In a similar way, fuzzy probability analyses have more or less accommodated negative probabilities in the form of crisp values. It has been demonstrated that fuzzy analysis is also being utilised instead of negative probability to avoid decades of controversy that trailed the negative probability concept (Pykacz 2006).

The HyCs values can be improved by meeting other requirements as specified for instance, when a crew undertake Crew Resource Management (CRM) course, his capability can improve. In the maritime industry, task instructions or procedures are an unreliable standard for judging behaviour, and in real situations; operator's initiatives will prevail over safety mechanisms or procedure to restore operability or improve efficiency. For an in-depth defence against failure, potential gaps and needs for operator rationality must be accounted in the taxonomy of operational boundary conditions. In this study, the gap generating function is the structural knowledge in the form of hypothetical constructs (HyC) scaled in the logic worksheet. Unlike component failures, human can change or recover depending upon the quality of crew, logistics, supervision etc. Modelling by task analysis can be useful when operator is rigidly constrained by systems control mechanisms such as in the aviation industry. When dealing with humans in maritime operations, we have to seek for models at higher conceptual level that will reveal and account for *latent issues*. The PSFs that impaired human performance can be exploited by careful study of human physical, psychological, logistical and working conditions.

> *Qualitative considerations, based on qualitative observations, are much more significant in determining the final probability*…(LeBot 2004).

The subjectivity in the allocation of probabilities in the CREAM method was clearly demonstrated by the author in Fujita and Hollnagel (2004)

Table 7-3- The Logic Worksheet - Quantitative Taxonomy of HEBCs into HyCs

HEBC	Latent Variables	Max Scores	Hypothetical Constructs variables (HyCs)		Probabilities
Crew Capability Audit -X1		0.133701			
	Knowledge	0.033			
			Higher degree		0.012
			Bachelors		0.01
			Diploma/equivalent		0.006
			School Cert		0.005
			Not educated		-0.002
	Skills	0.036			
			Hazard Perception		0.01
			Realisation of failure		0.005
			Diagnosing capability		0.005
			First-aid capability		0.002
			Reaction time		0.004
			Experience (Yrs)	Over 7 - Very Good	0.006
				4 to 7 - Good	0.003
				1 to 3 - Fair	0.001
				less 1 - Poor	0

	Health state	0.02			
			Very good		0.012
			Good		0.006
			Fair		0.002
	Psychological	0.02			
			Conscientiousness		0.04
			Openness		0.04
			Extraversion		0.04
			Agreeableness		0.04
			Neuroticism		0.04
	Anthropometric	0.01			
			Ability to lift, haul, pull, rescue		0.05
			To withstand fatigue or sea state		0.05
	Cultural/social status	0.015			
			Sociability	controlled drinking	0.01
				uncontrolled use of alcohol	-0.01
				Sports and recreation	0.005
Training-		0.12240			

X2		6			
	Routine - On the Job Training (OJT)	0.0408	Induction		0.011
			Application		0.03
			None		0
	Crew Resource Management	0.04081			
			CRM 1		0.021
			CRM 2		0.02
			None		0
	Professional	0.0408			
			Specialisation		0.02
			Operational Maintenance		0.021
			No training		0
Supervision-X3		0.114891			
	Proximity	0.05			
			First-line manager		0.025
			Remote monitoring		0.015
			Intermittent		0.01
			None		0
	Discipline	0.015			
			Very strict		0.01
			Moderate		0.005
			Loose		0
	Safety Culture	0.05			
			Strict and Proactive		0.04

			Reactive		0.01
			Loose		0
Logistics-X4		0.118248			
	Maintenance	0.01	In-house repair		0.005
			In-house servicing		0.002
			External repair		0.002
			External servicing		0.001
	Spares/tools	0.03			
			Spares/tools onboard		0.02
			Spares/tools by request		0.01
			Spares/tools inadequate		0
	Time/planning	0.01			
			Very good schedule		0.009
			Fair scheduling		0.001
			Operate under pressure		0
	Manning	0.023			
			Adequate - Navy standard		0.02
			Average		0.003
			Below average		-0.001
	Resource availability	0.023			

			Available		0.02
			Partially available		0.003
			Poor		-0.001
	Age of equipment	0.023			
			1 to 5 yrs		0.015
			6 to 10		0.005
			11 to 15		0.003
			16 to 20		0
			over 20		-0.001
Procedure -X5		0.120441			
	Standing instructions	0.02			
			Crew responsibilities		0.007
			Admin procedures		0.005
			Special instructions		0.008
			None		-0.005
	Normal operations	0.022			
			Stop procedure		0.008
			Start procedure		0.006
			Monitoring		0.008
			Not provided		-0.005
	Emergency	0.04	Stop		0.005

	operations		procedure		
			Start procedure		0.015
			Monitoring		0.005
			Feedback		0.015
			Not available		-0.01
	Test procedures	0.016			
			Yes		0.016
			Not available		0
	Alarm systems	0.022			
			Yes		0.022
			Not available		0
Communication-X6		0.109091			
	System	0.04			
			Adequate signs		0.02
			Poor signs		0
			No signs		-0.01
			Adequate tagging		0.021
			Poor tagging		0
			No tagging		-0.01
	Transmission	0.005			
			Direct		0.0025
			Indirect		0.0025
			Not defined		0
	Feedback	0.03			
			Crew response index		
			- fast		0.01

			- slow		0.005
			Documentation of adaptations		
				Written	0.01
				Verbal	0.005
				No instruction	-0.01
	language	0.005			
			Clarity - good		0.005
			Clarity poor		0
	shift handing over	0.03			
			Written procedure		0.015
			Supervised verbal		0.01
			Unsupervised verbal		0.005
			Casual		-0.01
			In absentia		-0.01
Welfare-X7		0.099888			0.015
	Individual hierarchy	0.02	Management		0.01
			Supervisory		0.008
			Crew		0.002
			Novice/trainee		0
	Job description	0.01			
			Commensurate to status		0.01

			Deviation from status		0
			Below status		-0.01
	Incentives	0.03			
			Tangible Stimulus		0.02
			Intangible stimulus		0.01
			No incentive		0
	Remuneration	0.04			
			Adequate/above standard rate		0.03
			Standard rate		0.01
			Below standard		0
			Constrained		-0.005
Stress-X8		-0.099147			
	physiological	0.049574			
			Fatigue		0.015
			Hunger		0.005
			Pain		0.005
			Circadian rhythm		0.015
			None		0
	psychological	0.049574			
			Task speed/load		0.01

			Task complexity		0.015
			Sound mind		0
Environment-X9		-0.081327			0.05
	Motion sickness	0.05			
			Rough sea		0.04
			Moderate		0.01
			Calm sea		0
	Noise/vibration	0.021			
			Machinery		0.015
			Sea		0.001
			Others		0.005
	Temperature	0.01	Machinery		0.005
			Sea		0.003
			Others		0.002

The logic of analysis in this initiative is iterative and progressive. Analysis can be carried out in a continuous continuum by refinement of data or operational boundary conditions. All possible predisposition sources of human error must be sorted out in a step by step manner Irrespective of detail, effort or time required. Practical oriented strategy and idyllic situation in operations, have been highlighted by pointing out '*pre-accident human factor*', and the manifestation of the accident precursor in the form of latent factors (LeBot 2004). In the development of HEBC, the tripartite failure mode concept was uncovered. As a result based on current findings generated from data obtained, entropy refers to the underlying human-machine disorderliness in the form of:

cognitive-based errors and violations (with no sabotage). The structuring and breakdown of HEBC into construct variables reveals operator variables like; skills, psychological and anthropometric features for guidance and ease of application (Broadbent 1982; Wiggins 1996). The HyCs allow operators, to operate even within the risk zone and can therefore be generic, towards the development of '*Resilient Engineering'* for maritime application. After, all it also human to *err* (Kohn and Donaldson 2000; Hollnagel, 2006).

7.11 Conclusion

This Chapter has illuminated on the research findings, concept and acronyms of *HEBCs* and *Human Entropy and Hypothetical Construct Variables*. The evolution of human entropy has widened the horizon and scope of HRA and demonstrated how the human entropy can be controlled. Human disorderliness in maritime operations is a result of complex and interlinked actions of crew, management and environmental condition which can be overt or covert and in each case accident can only happen when operational boundary conditions are cracked open. The confluence of tripartite human failure modes in operation is what characterises the accidents. The HyCs provide the logical thought process in the form of discrete steps for the analyst to evaluate performance conditions and therefore, permits diverse phenomena to be interpreted in a common way. The HyCs approach does not entail rigid adherence to premature theory, on the contrary, HyCs can be viewed as theory-based hypothesis that can be tested empirically. Thus, constant theorising is necessary to give meaning and direction to observation and experimentations. In the Logic Worksheet, the HyCs variable probabilities are designated with a mathematical sign; plus or minus (+/ -). The positive and negative signs indicate what safe practice will entail for successful operations or constraints that could potentially reduce performance. The inferred probability values in the Logic worksheet can be improved by meeting other requirements. By observing behaviour and utilising this unified and organized approach, predictions of behaviour can be generated. However, one of constraints in the operationalisation of the HyCs is limiting the scope of the main variable (the HEBCs) e.g, when evaluating culture, this can be done in terms of; lack of a social life, low self-esteem etc.

CHAPTER 8. HENT Model – Concept and design

8.1 Introduction

The concept of human error, whether intentional or unintentional, was defined as:

'Any human action or lack thereof, that exceeds or fails to achieve some limit of acceptability, where limits of human performance are defined by the system' (Lorenzo 1990).

The human factor research involves affiliation of the man-machine interface with the environment in which the crew operates his/her system. However, the operator's success is based on a number of issues such as: operational guidelines, operator skills, and workplace communication etc. Following research works and experimentations, the get through in the study of human factors was the propensity to identify opportunities for human failures by means of performance shaping factors (Park and Jung 1996; Mackieh and Cilingir 1998; Toriizuka 2001; Kim and Jung 2003). The Performance Shaping Factors (PSFs) were initially advanced by the behavioural scientists and have since then been used to model human factor (Gertman and Blackman 1994). Subsequently, HRA was dominated by the behavioural scientists, even when it involves technical systems. As such, HRA models were inhabited in theories of task analysis and error type, far away from the operational technical criticalities and realities (Swain, 1989). Additionally, validations carried out even on major HRA assessments yielded contradictory results (Boring, et al. ; Kirwan 1996). Hence, because of the complexities in man-machine interface, there has been a move by system engineers towards reducing the dominance of psychologists and to return human factor to the appropriate discipline (Byrne and Gray 2003). In maritime operations, human-system endeavour is even more complex because the environment in which the crew operates is marred with chaotic uncertainties ranging from complex systems and rough weather, to sleep disruption and work stress etc. These issues have made it imperative for a more robust system engineering approach to come to bear in predicting operational risks. Thus, in this initiative, the Human Entropy (HENT) model was specifically designed to quantify the criticalities in human system endeavour. This Chapter presents the human reliability analysis model for maritime applications and is called *Human Entropy Model.* The evolution of HENT and Human Entropy Boundary Conditions (HEBCs) were discussed in the preceding Chapters. The concept of human entropy is to exploit all forms of human endeavour in operation with a view to deliver holistic safety assessment.

8.2 Premise of HENT Model

The increasing changes in technology are always accompanied by new unknowns that pose a threat to crew capabilities and increase proneness to disorderliness. In maritime operations, the job imposes certain demands on crew and the crew is required to deliver based on skills, knowledge, logistics, etc. The human entropy model is one reliability assessment tool that can predict operational state of readiness by screening operational standing at any instance. The modelling is conceived by scaling HEBC into quantifiable Hypothetical Construct (HyC) variables and the logic of the analysis is iterative and progressive in a continuum by refinement. The HENT model extends the scope of boundaries of HRA in the context of what needs to be considered by incorporating human disorderliness (entropy) in addition to error. This initiative will potentially minimise failure due to operational latent factors. The analytical logic which will be discussed later in this chapter is depicted below, in Figure 8:1.

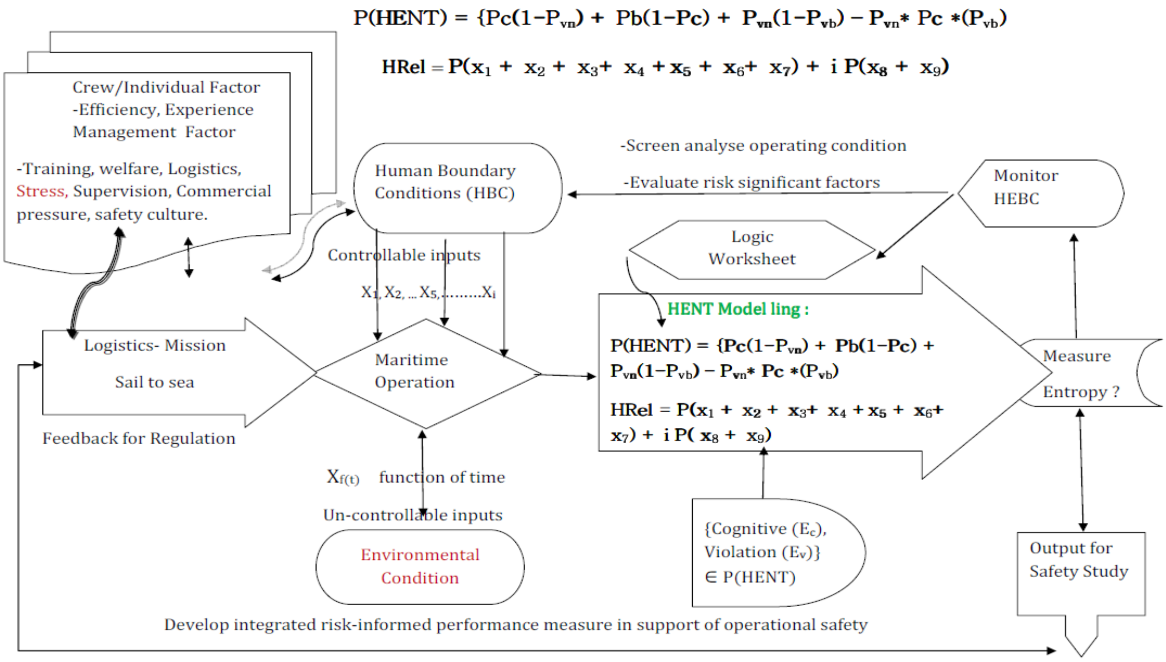


Figure 8:1 – HENT Modelling Concept

8.3 HENT Model - Modus Operandi

The evolution of human entropy (HENT) has resulted in the recognition of *tripartite* human failure modes; cognitive error, negligence and breach. These failure modes are inevitable in the maritime environment and manifest as consequences of operational boundary conditions. The HENT modelling technique unveils unsafe acts and deviations from standard practices and is therefore, proactive in design because it utilises hypothetical construct variable (HyCs). The HyCs utilities indicate what safe operation should comprise, devoid of failure and also, operational constraints which could trigger bounded rationalities and extraneous acts. These constraints point to operationally undesirable conditions which could cause failure. However, these constrains could be surmounted by available adaptive capacity such as; high crew capability, adequacy of logistics, supervision etc. Thus, the adaptive capacity of any system is a function of its systemic resiliency to failure and operating crew resiliency. In the HENT model the resiliency is judged by utilities which resists disruptions and supports adaptability within operational boundary conditions. The HENT model is also a safety assessment tool in which the quantification and safety audit can be achieved by the following methods:

1) Safety predictions by using tripartite failure modes

2) Holistic human reliability analysis using human entropy boundary conditions

8.4 Quantification Using Tripartite Failure Modes

The tripartite human failure modes are mathematically coupled as shown in Figure 8:2:

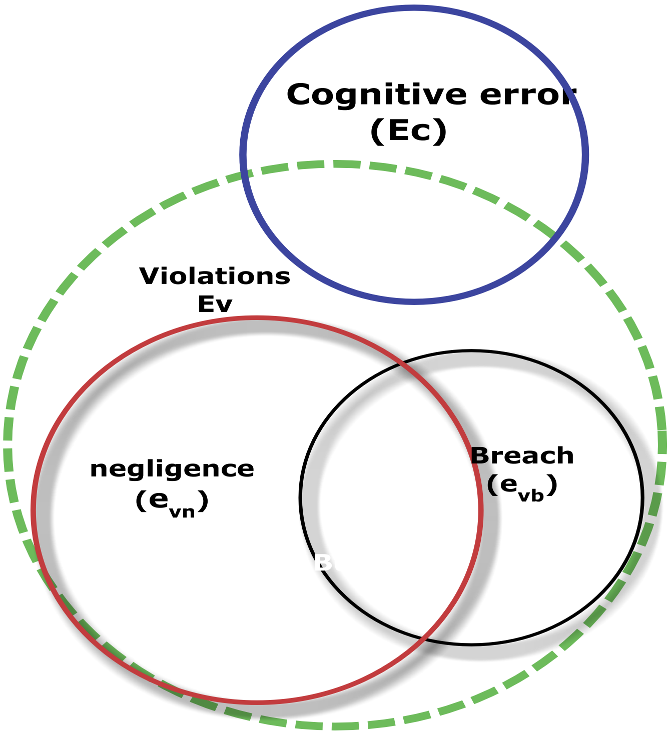


Figure 8:2 – Tripartite Human Failure Modes -Dependencies

Where:

Ec = Cognitive error; $\boldsymbol{E_v}$ **= V**iolations;

e_{vn} and e_{vb} represent negligence and breach respectively;

e_{vn} and e_{vb}, are subsets of $\boldsymbol{E_v}$**.**

8.1 Assumptions:

1) $Ec \cap Ev \neq \emptyset$ [E_c and E_v not mutually exclusive]
2) $E_v \approx (e_{vn}) \cup (e_{vb})$ [with no sabotage]
3) $(e_{vn}) \cap (e_{vb}) \neq \emptyset$

By taking the probabilities of the events: Ec and Ev,the probability (P) is the probability that human entropy or disorderliness (HENT) manifests.

Therefore, using the event relationships shown in Figure 8:2 above and judging by using the probability model shown below in Figure 8:3:

$$P[HENT] = P\{(E_c) \cup (E_v)\} \tag{8:1}$$

By taking the probability of the events in equation (8:1)

$$P[HENT] = P(E_c) \cup P(E\cap_v) - P(E_c \cap E_v) \tag{8:2}$$

Where;

$$P(E_c \cap E_v) = P(E_c) * P(E_v) \tag{8:3}$$

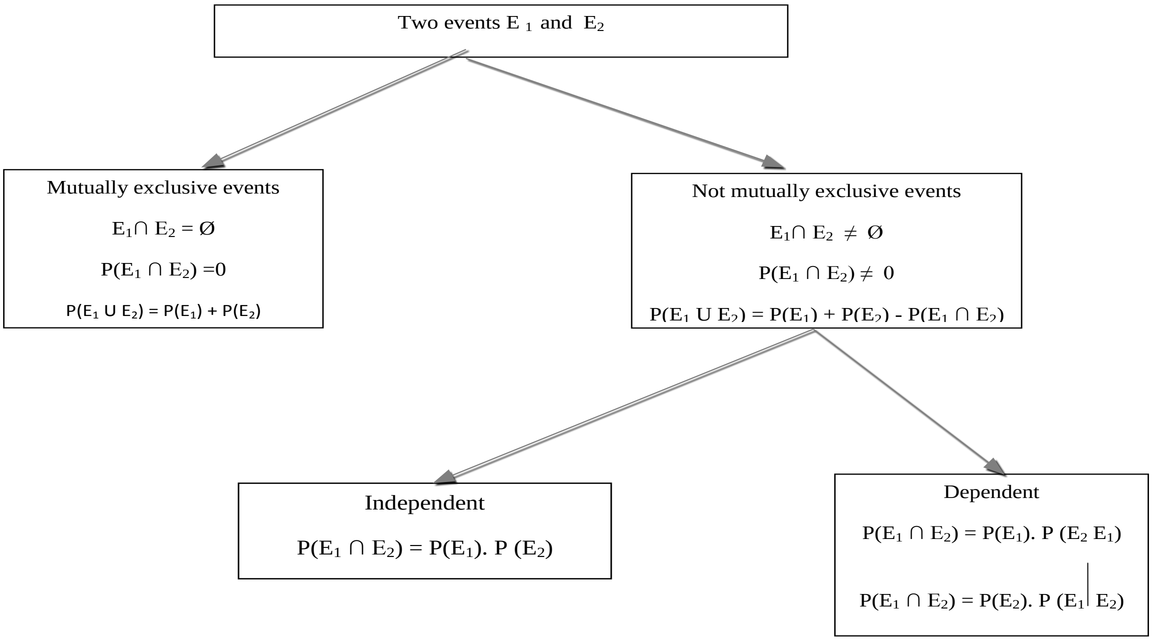


Figure 8:3 – Model for the Probability of Events (Courtesy: Andrie, 2008)

Substituting equation (8:3) into equation (8:2):

$$P[HENT] = P(E_c) + P(E_v) - P(E_c) * P(E_v)$$

Therefore, from Figure 8:2;

$$P\ (E_v) = P\ (e_{vn}) \cup P\ (e_{vb}) – P\ (e_{vn} \cap e_{vb}) \qquad (8:4)$$

$$P(E_v) = P(e_{vn}) + P(e_{vb}) – P(e_{vn}) * P(e_{vb}) \qquad (8:5)$$

Substituting equation (8:5) into equation (8:4),

$$P(HENT) = \{P_c(1-P_{vn}) + P_b(1-P_c) + P_{vn}(1-P_{vb}) – P_{vn}* P_c *(P_{vb}) \qquad (8:6)$$

HENT failure modes (cognitive error, negligence and breach) are consequences of the HEBC utilities or performance parameters. By changing the state of the HEBCs, the human entropy can be reduced or increased. The HEBCs are composed of positive and negative utilities as shown in the logic work sheet in the preceding Chapter. The utilities with positive signs enhance human reliability, while those with negative signs represent constraints and potentially, reduce human reliability and are therefore treated as impedances in the computation. Tripartite failure modes are inversely proportional to positive HEBCs. This is because, the higher the positive human entropy boundary conditions, the less the chance of failure. Therefore, this is represented as

$$P(e_c, e_{vn} \text{ and } e_{vb}) \ \alpha \ \frac{1}{HEBC} \text{Ŧ}_{\text{entropy}} = K \frac{1}{HEBC} \qquad (8:7)$$

Where:

$\text{Ŧ}_{\text{entropy}}$ is the tripartite failure mode function

$\text{Ŧ}_{\text{entropy}} = f(e_c, e_{vn}, e_{vb})$;

The sum of the positive (enhancing) human entropy boundary conditions is given as:

$$\text{HEBC} = \sum_{i=1}^{7} P(Xi)$$

K is proportionality constant in the expression in equation (8:7); P is the entropy probability, while subscripts *c*, *vn* and v*b* represent cognitive, negligence and breach failure modes, respectively. Graphically, representing two inversely proportional variables creates a hyperbolic curve in the Cartesian coordinate plane. Therefore, because both variables cannot be zero, the constant K is the product of the two utilities at any point of the curve.

$$\text{Ŧ}_{\text{entropy}} = f(e_c, e_{vn}, e_{vb}) = K \frac{1}{\sum_{i=1}^{7} P(Xi)} \qquad (8:8)$$

Equation (8:8) implies that:

$$e_c = K_c \frac{1}{\sum_{i=1}^{7} P(Xi)} : e_{vn} = K_{vn} \frac{1}{\sum_{i=1}^{7} P(Xi)} : e_{vb} = K_{vb} \frac{1}{\sum_{i=1}^{7} P(Xi)}$$

Equations (8:6) and ((8:8) were derived to provide means of predicting human entropy directly or indirectly. The applications for these equations are provided below.

8.4.1.1 *Application of Equation (8:6)*

Equation (8:6) is designed to measure human entropy. This can be realised by exploiting industry recorded incident/accident data bases. Current set values for the tripartite failure modes differ from one industry to the other due to varying level in safety enforcement and compliance.

The values for tripartite human failure modes were obtained by reviewing maritime accident data bases and rounded up by experts as discussed in Chapter 6 and shown below.

- Cognitive error = $e_{c\,=}$ 0.22 (P_c = 0.22)
- Negligence = $e_{vn\,=}$ 0.60 (P_{vn} = 0.60)
- Breach = $e_{vb\,=}$ 0.17 (P_{vb} = 0.17)

Where, subscripts *c*, *vn* and v*b* represent cognitive, negligence and breach failure modes respectively and P is the probability of occurrences.

By substituting the tripartite values (e_c , e_{vn} and e_{vb}) into equation (8:6);

$P(HENT) = \{P_c(1- P_{vn}) + P_{vb}\,(1-P_c) + P_{vn}\,(1- P_{vb}) – P_{vn} * P_c *(P_{vb})$

$= \{0.22(1-0.60) + 0.17(1-0.22) + 0.60(1-0.17) – (0.22)*(0.17)*(0.60)\}$

$= (0.7186) - (0.0224) = 0.70$

P(HENT) = 70.0%

From the above result, current industry status indicates that human entropy is 70.0%, meaning the contribution of humans to failures is over 70%. It is therefore, accurate to state that over 70% of all maritime time accidents are due to human entropy; error, negligence and breach of safety. This value is quite comparable to what is obtained from the literature reviews on the human contributions to failure. Various studies have indicated that human contribution to failures can be as high as 70% or more (Sanders and McCormick 1987; Bea, 1998; Hee ,et al. 1999; DiMattia et al. 2005). This represents the value based on statistics obtained from different industries and in this case for maritime industry it represents the minimum human contribution to failure.

8.4.1.2 *Application of Equation (8:7)*

$$Ŧ_{\text{entropy}} = K \frac{1}{HEBC} \quad K_{c\,=}\, e_c * \sum_{i=1}^{7} P(Xi) \qquad (8:7)$$

By substituting the values of Xi as provided in Chapter 7, Figure7-6, (the human entropy boundary conditions) we obtain;

$$\sum_{i=1}^{7} P(Xi) = 0.818666$$

$$K_{c\,=}\, e_c *(0.818666)$$

By substituting the value of each tripartite failure mode ($e_{c\,=\,0.22\,;}\, e_{vn\,=\,0.60;}\, e_{vb\,=\,0.17}$) ,the K value s are as follows:

$$K_c = 0.1801K_{vn} = 0.4911K_{vb} = 0.1391$$

With the K values as constant, human entropy can be calculated using the human entropy boundary conditions (HEBC) as given in equation (8:6). Each organisation or industry can obtain its K values by commissioning experts to review its accident/incident data bases extract tripartite human failure modes ($e_{c;}$ e_{vn} and e_{vb}). The tripartite failure modes can be weighted and normalised to unity; values obtained can then be substituted into equation (8:6) to determine the industry entropy.

8.5 Quantification Using Human Entropy Boundary Conditions (HEBCs)

In this design, the human reliability can be computed by utilising the hypothetical constructs of human entropy boundary conditions. This can be achieved by segregating the positive and negative (retarding) utilities as follows:

HENT α (+ve $\frac{1}{\text{HEBC}}$) (Inverse proportionality with +ve utilities)

HENT α (-ve HEBC) (Directly proportionality with -ve utilities)

The human entropy can be reduced by increasing values for positive utilities of HEBC.

The human entropy (human disorderliness') increases with increase in operational constrains (negative HEBC utilities), in other words, HENT is proportional to negative HEBC. Therefore, by combining the above expressions;

$$\text{HENT} = \frac{\sum -ve\ HEBC}{\sum +ve\ HEBC} = \frac{[Impedence\ Probabilities]}{[Success\ \ Probabilities]}$$

(8:81)

This relationship is akin to Ohm's law of electricity with respect to current flow in an electrical circuit shown in Figure 8:4 below. The Current [I] is directly proportional to Voltage [V] and also, inversely proportional to the Resistance [R] of the conductor which also yields the following relationship:

I α 1/R and I α V

Combining the above relationships implies:

$$I = \frac{V}{R} \qquad (8:9)$$

Hence equation (8:8) is analogues to equation (8:9).

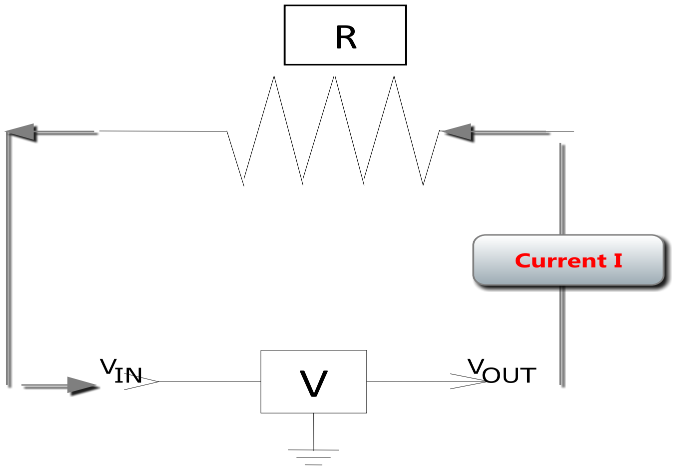


Figure 8:4 – Flow of Electricity in an Electrical Circuit

Here resistance [R]constitute the impedance by resisting the current [I]. Similarly, the stressors slow down the human effort and create a state of uncertainty. Since HENT constitute the disorderliness and the maximum reliability sums up to unity then:

$$\text{HRel} = 1 - \text{HENT}$$

Where: HRel represent the human reliability for marine and offshore industry;

$$\text{HRel} = 1 - \frac{\sum -\text{ve HEBC}}{\sum +\text{ve HEBC}}$$

$$\text{HRel} = \frac{\{\sum +ve\ HEBC - \sum -ve\ HEBC\}}{\sum +ve\ HEBC} \qquad (8:20)$$

Therefore, the Human reliability is evaluated as:

HRel = (sum of positive HEBC – sum of negative HEBC) / sum of positive HEBC

$$(\sum +\text{ve HEBC}) = \sum_{i=1}^{7} \mathrm{P}X\text{i:}); \text{ and } \left(\sum -\text{ve HEBC}\right) = \sum_{8}^{9} \mathrm{P}X\text{i}$$

The failure modes (cognitive, negligence and breach) are consequences of HEBC's and the prevalence of each human failure mode can be reduced by changing the state of the HEBC's utilities. For instance, close supervision can reduce error and negligence; similarly, adequate logistics can reduce acts of breach by preventing unprecedented additions and alterations etc. In this design, the HEBC values have been constructed in a probability continuum from the logic worksheet. The HEBC's construct variables are the determinants, therefore useful in suggesting the operational status. Each of the intervening construct variables is assigned a mathematical sign (positive and negative) depending on the operational conditions. The scaling of the numerical values was designed top down in descending order (high reliability values at the top). Each chosen variable measures is specific factor (independently) not to be found in any of the other variables.

8.6 Real and Imaginary Components of HENT

Since work stress and sea state cannot be predicted to a greater accuracy, these boundary conditions will be treated as imaginary quantities. The idea of real and imaginary components is to distinguish between what is measurable and predictable and what is not. Though most of the human entropy boundary conditions were evaluated by subjective means, the stressors proved chaotic and most unpredictable as will be discussed later. It is thus, necessary to create segmentation in the form of real and imaginary utilities. This will also provide flexibility, prudency and clarity in reporting HRA results by deciding which factors are measurable and which are inferred.

8.6.1.1 ***Real Component of HEBC***

There are seven positive HEBC (enhancing conditions) which shall be called the real components. The real components decrease the human entropy, in other words, improve human performances and reliability. However, once certain safety conditions or operational requirements are not met, the real boundary condition components may take a negative sign. This can be seen rationally from the top down arrangement or the descending order in probability of success. The positive HEBCs are:

1) Crew Quality (X_1)
2) Training (X_2)
3) Supervision (X_3)
4) Logistics (X_4)
5) Procedure (X_5)
6) Communication (X_6)
7) Welfare (X_7)

8.6.1.2 ***Imaginary Components of HEBC***

The imaginary components are those components that can only be inferred and require robust scientific analysis and tool to quantify. There are two imaginary components which can only be measure through fictitious assumptions;

1) Work stress - (E_4)
2) Environmental factors - (E_5)

Imaginary HEBCs are like the *impedance* in an electric circuit and therefore, constraints to safe operability. Impedance increases the chance of human entropy through unpleasant conditions for the human operator. Stress and sea environmental conditions have been discussed in the preceding Chapters. Sea effects on crew (X_9) can potentially increase work stress and will psychologically induce fear and depression due to isolation and uncertainties. Bad weather condition increases the demand for continuous lookouts against risks posed by glaciers, ice, poor visibility and wrecks, traffic and even the machinery operational state can be uncertain etc. These circumstances create potentials for human error, negligence and breach by whatever means to sustain systems persistence. Thus, until technology eliminates sea effects and work related stresses, human reliability in marine operations will surely suffer some setbacks.

Because the imaginary components are complex in nature and need to be accounted for in the HRA, an engineering approach was adopted. This is done by mapping the HRA components onto an Argand Diagram, seen in Figure 8:5. The Argand Diagram shows the real component on the abscissa and the imaginary on the ordinate axis (Pearson 2000). In engineering disciple, the concept of imaginary evolved to represent quantities which are fictitious and immeasurable but practically exist. Further discussion on the interrelation of the human entropy boundary conditions follows below.

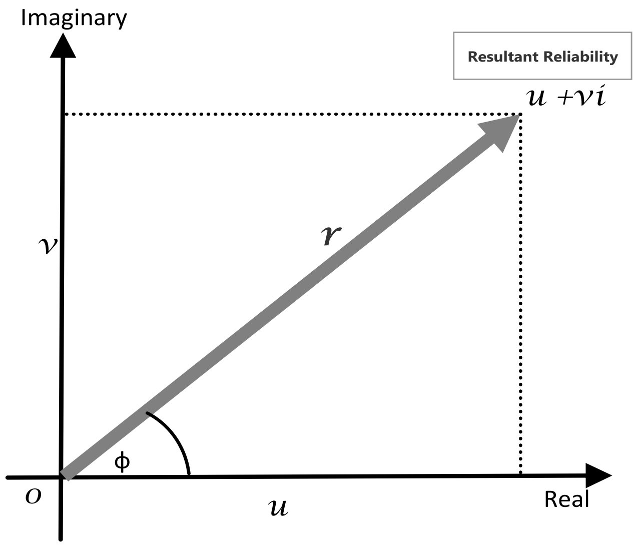


Figure 8:5 - Argand Diagram

$$r = u + iv \qquad (8:31)$$

Equation (8:10) was derived from Figure 8:5, with the symbol i indicating the imaginary component. The modulus |Z| is given as:

$$|Z| = \sqrt{u^2 + v^2}$$

Using polar coordinates r and ϕ (representative angle),

$$\phi\ (u, v) = (r \cos \phi, r \sin \phi); (r, \phi) = (\sqrt{u^2 + v^2}, \arctan {}^{u}/_{v})$$

The representative equations in trigonometric form with e as the natural logarithm are (Feynman and Richard 1977):

$$\cos \phi = \mathrm{Re}(e^{iu}) = \frac{e^{iu} + e^{-iu}}{2};\ \sin \phi = \mathrm{Im}(e^{iu}) = \frac{e^{iu} - e^{-iu}}{2i}$$

The above idea follows intuitively to the following discussion.

8.7 Human Entropy Boundary Conditions - Relativity

Figure 8:6 shows cross correlation of the components and depicts how they are coupled making real analysis of a problem complex. Each of the components is identified by the letter ‘E’ which signifies an event.

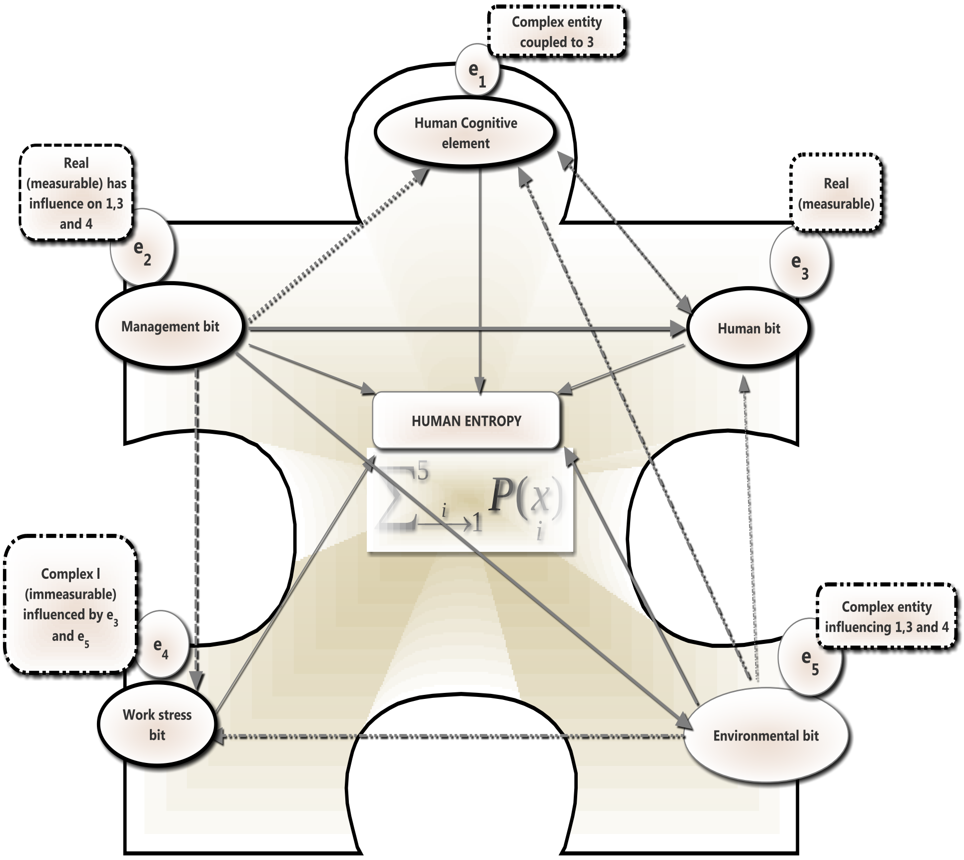


Figure 8:6 - HENT Computational Resources

9.1 The Human Component (e_3)

This component is most significant because it provides utilities which can be used to carry out assessment of crew risk index. The human component is potentially responsible for cognitive error; and in this context, failure may be due to errors of omission/commission, slips, fumbles, lapses, etc. The crew are also predisposed to extraneous acts and all forms of volitional acts such as operational ETTO (efficiency thoroughness trade-offs). In the HENT design, provision has been put in place which can evaluate the Crew Capability Audits (CCA). The CCA is a measure that can predict crew resiliency, adaptability, and vigour and the ability to deliver positive results. The CCA utilities is a powerful tool that is capable of providing information on crew ability (Raby and Mccallum 1997). The predicted result generated from the CCA provides the Crew Quality Index (CQI) and the higher the CQI the higher the crew reliability and resiliency. Lower values of CQI are a pointer to weaker crew. Therefore, such crew with low CQI will be pre-disposed to higher risks, proneness to error, extraneous acts and breach safety rules. From Figure 8:6, it can be observed how the human component (e_3) is coupled and influenced by other components such as the stress, management and environment.

8.7.1.1 ***The Management Component (e_2)***

The management component is composed of utilities which measure management resiliency to system, extraneous acts and local rationality. The management contributions to operational success or failure can be in the form of: corner cutting, profiteering, negligence in maintenance, failure to supply logistic requirements, inadequate planning, disregard weather forecast, etc. Management are also responsible for ensuring the optimal man-machine interface (MMI), e.g., ergonomics, operational flexibilities to reduce crew stress and task complexity, equipment redundancy, responses to the crew demands etc.

Figure 8:6, shows how the management bit (e_2) is coupled to crew bit (e_3) and environment (e_5).

8.7.1.2 *The Imaginary Bits (e_4) and (e_5)*

The environmental component (e_5) addresses the effects of the ocean and the weather conditions on the crew. The environmental bit is coupled to work stress (e_4) on crew thus, aggravating crew condition. Therefore, the work stress bit (e_4) is also influenced by management (e_2) and environment (e_5). This combination makes the situation complex and not readily quantifiable. Maritime transport takes long period of time to deliver as such; within operational space and time, a state of "*cognitive complexity*" (CC) may be reached which creates adverse effect on the crew. This is due to interactivity during the sailing period and that will adversely affect the human component (Pervin, 1984). The CC makes real analysis of problems complex; human cognition will be cognitively improbable; it is easier to exemplify than to quantify.

Using Boolean algebra:

$\text{Imaginary (Im)} = [(E_4) \cup (E_5)]$

Substituting the HEBCs (stress (X_8) and environment (X_9) utilities)

$$\text{Imaginary} = i\,\{x_8 + x_9\} \qquad (8{:}42)$$

$$\text{Real} = \{(E_2) \cup (E_3)$$

$$\text{Real} = (x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7) \qquad (8{:}53)$$

Using this classification, the results of the human reliability analysis are in two parts, imaginary (Im) and real (Re), as shown in Figure 8:7

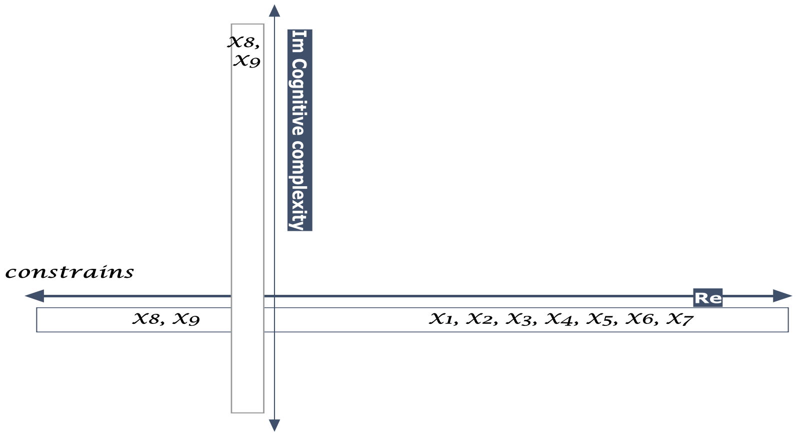


Figure 8:7 - Human Entropy Complex Plane

Therefore the Theoretical Human Reliability (THRel) can be expressed as:

$$\text{THRel} = \text{Re} + \text{Im}$$

$$\text{THRel} = (x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7) + i\,(x_8 + x_9) \qquad (8{:}64)$$

Equation (8:14) provides the theoretical realities. From this design, it is possible to see what is controllable and what is not. The combine effect of stressors on crew can be clearly appreciated from the design in Figure 7.6.

Thus, the human reliability can be computed by substituting values into Equations (8:10) as follows:

$$\text{HRel} = \frac{\{\sum +ve\ HEBC - \sum -ve\ HEBC\}}{\sum +ve\ HEBC} \qquad (8{:}10)$$

$$\text{HRel} = \frac{\{\sum Rel - \sum Im\}}{\sum Rel}\ \text{(from complex plane)}$$

Therefore

$$\text{HRel} = \frac{\{(\text{x1} + \text{x2} + \text{x3} + \text{x4} + \text{x5} + \text{x6} + \text{x7}\ ) - \{(\text{x8} + \text{x9})\}}{(\text{x1} + \text{x2} + \text{x3} + \text{x4} + \text{x5} + \text{x6} + \text{x7})} \qquad (8{:}75)$$

Hence, Equation (8:14) provide the theoretical expression while, Equation (8:15) gives the practical way in which the human reliability can be evaluated.

8.7.1.3 *Applications*

These analyses provide a framework in which the Human Reliability Analyses (HRA) can be most transparent and provide a platform for mitigation considering operational constrains. Similarly, by decomposition, the operator's risk and management bits can be independently measured as follows:

Measure of Crew Quality Index (CQI)

The Crew factor is composed of utilities which define what credential/quality a competent crew should have to deter accidents. Therefore, in this initiative a Crew Capability Audit was designed to provide a measure of each crew member's residual risk. Each individual Crew Quality Index (CQI) can be obtained. Aggregated risk index of personnel in a ship can then be obtained by summing up the quality audit results, thus;

Total Crew Reliability = $\mathrm{f(CQI)} = \sum_{\mathrm{n=1}}^{\mathrm{m}}(\mathrm{CQI}_1 + \mathrm{CQI}_2 + \ldots\ldots + \mathrm{CQI}_\mathrm{m})$

8.8 Worked example of how to measure Crew quality

Assume we have a Crew whose name is Mrs Lion's. Based on Mrs Lion's record and interviews conducted by assessor (expert) using the Logic worksheet in Table 8:1, the following data about her was generated:

1) Knowledge = 3.05 (out of 3.3)
2) Skills = 3.0 (out of 3.6)
3) Health state = 1.2 (out of 2.0)/

4) Psychological = 1.1 (out of 2.0)

5) Anthropometric = 1.0 (out of 1.0)

6) Cultural/social = 0.8 (out of 1.5)

Mrs Lion’s TOTAL CQI = $\sum_{n=1}^{6}(CQA_{utilities})$

The CQA utilities are shown in the HyCs variable Logic worksheet, Table 7-1. These utilities were plotted on graph which is shown Figure 8:8. Therefore, Figure 8:8 shows a plot of Crew quality audit utilities ($CQA_{utilities}$) obtained from the Logic work sheet with six utilities. The plot can be used as the datum to gauge or measure Mrs Lion’s quality index. Therefore, Mrs. Lion’s efficiency or reliability can be determined as follows:

CCA = Maximum value (obtained from logic worksheet) = X_1 = 13.4

Crew Quality (CQI) = 10.6

Crew Efficiency (η_{Ceff}) = CQI/CCA

= ${}^{10.6}/_{13.4}$

Therefore,

η_{Ceff} = 79.01%$\underline{\eta_{Ceff} = 79.01\%}$

From the results shown above, Mrs. Lion’s crew quality index is 79.01% and by inference, Mrs. Lion’s residual risk = (1 – 0.7901**)** = **0.209.**

The residual risk derived for each crewmember will guide management in allocating responsibilities and supervision levels commensurate to each crew member.

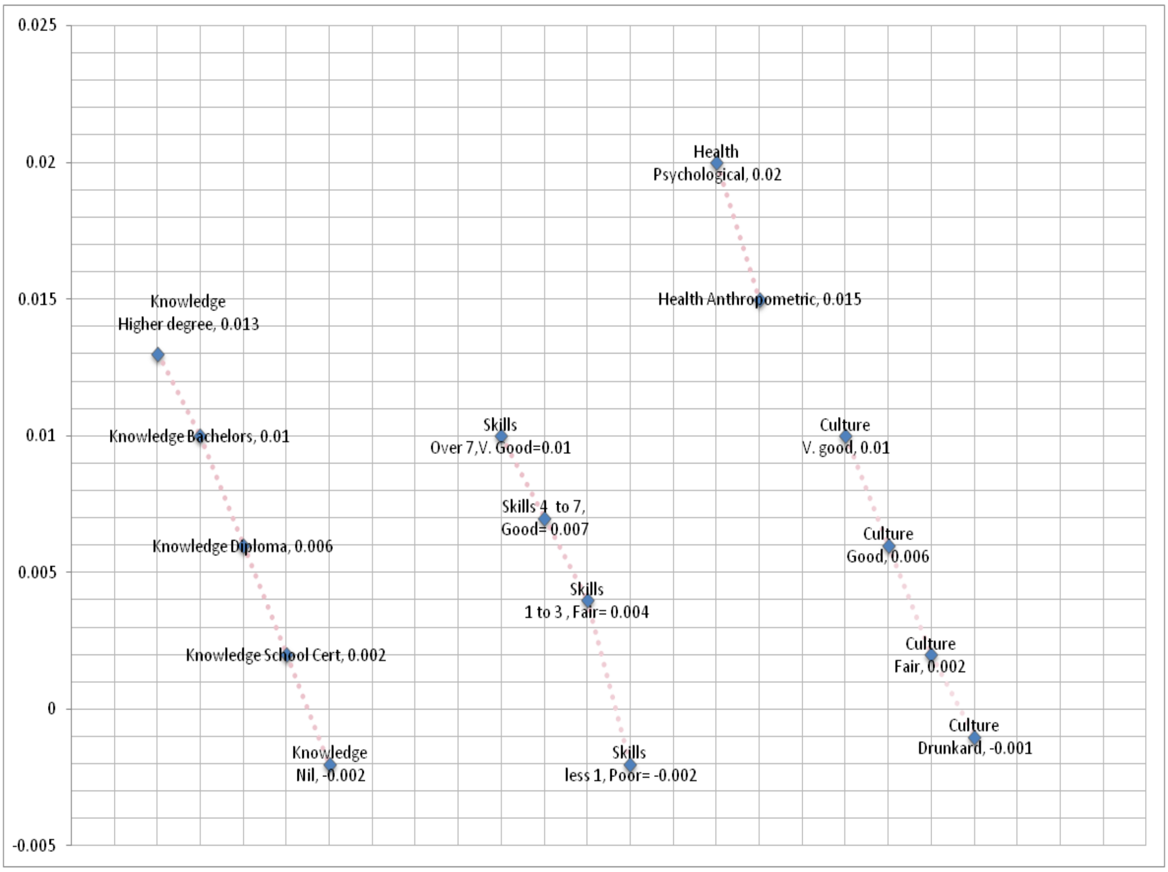


Figure 8:8 - Crew Capability Audit Utilities

Management Factor

In a similar way, the management factor can be evaluated as a function of HEBCs (X_2 through to X_8) as shown in Table 8-1 below.

Therefore,

Management Factor = $f(Mgt) = \sum_{n=2}^{8} P(X_i)$ (8:87)

The management factor will clearly indicate how the management influence and contribute to human entropy in operations.

Table 8-1 – Praxis of Human Entropy Components into HEBC Utilities

HEBC	Human bit (E_3)	Management factor (E_2)	Imaginary (E_5 and E_4)
X_1	Crew quality index	-	-
X_2	-	Training	-
X_3	-	Supervision	-
X_4	-	Logistics	-
X_5	-	Procedure	-
X_6	-	Communication	-
X_7	-	Welfare	-
X_8	-	-	Stress
X_9	-	-	Environment

8.9 Computation of Human Reliability

From the foregoing discussions, the complexities in human reliability will very much be appreciated. If however, the HRA results are not articulated into various components (as suggested in this study), the quantification will generate misleading results. In this design, the impact of each utility of the human entropy boundary conditions was assessed independently and the aggregated absolute value sums up to unity. The results are further summarised at Table 8-2 showing maximum and minimum values of Real and Imaginary components obtained from the logic work sheet. The values in Logic worksheet, forms the datum for HENT computation. The maximum values were obtained by setting all the Real HEBCs to maximum and the stressors (imaginary) to a minimum of zero. The minimum values were obtained in a similar manner but by taking maximum disturbance conditions of the stressors. The quantification depends upon the status of hypothetical construct variables at any point in the operational space. The HyCs dictate the values to be assumed by each HEBC (X_1 through to X_9). Considering equation (8:14), the maximum and minimum values can be predicted (maximum ($HRel_{Max}$) and minimum ($HRel_{Min}$) as follows:

$$THRel = (x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7) + i\,(x_8 + x_9) \qquad (8:18)$$

Substituting values from Table, the maximum ($HRel_{Max}$) and minimum ($HRel_{Min}$) are given as follows:

$$HRel_{Max} = 0.81866 + i0.180474$$

Table 8-2 - Maximum and Minimum Reliability Values

Event	HEBC	Probability of success (Absolute)	Imaginary maximum	Real Maximum
X_1	CQA	0.133701	--	0.133701
X_2	Training	0.122406	--	0.122406
X_3	supervision	0.114891	--	0.114891
X_4	Logistics	0.118248		0.118248
X_5	Procedure	0.120441		0.120441

X_6	Communication	0.109091	--	0.109091
X_7	welfare	0.099888	--	0.099888
X_8	stress	0.099147	0.099147	0
X_9	Environment	0.081327	0.081327	0
TOTAL	=	0.99914	0.180474	0.818666

Therefore based on this study the maximum attainable human reliabilities for maritime operations; is 81% with a disturbance of 18% (Operational impedance or stressors). The stressors or operational impedance are seemingly inevitable. Unless technology eliminates sea effects and work stress, 99% human reliability cannot be guaranteed as it is not attainable. It is therefore necessary to incorporate and embark on human and system resiliency to avoid mishap. This calls for more vigilance and robust design for all maritime systems. By this finding, the chances for human entropy are 18% and this value could result in failure due to human error, negligence or by breach of safety mechanisms.

8.10 The HENT Software

The HENT reliability software is a multi-utility tool designed to measure operational reliability for maritime industry. The HENT software is so designed as to support and provide the following probabilistic features and benefits:

1) Individual and Aggregate Crew Quality Audit

2) Management influence and risk factor against safe operability

3) Information on stressors and constraints to safety

4) Potential environmental impact on Crew against safe operations

5) Aggregated human reliability

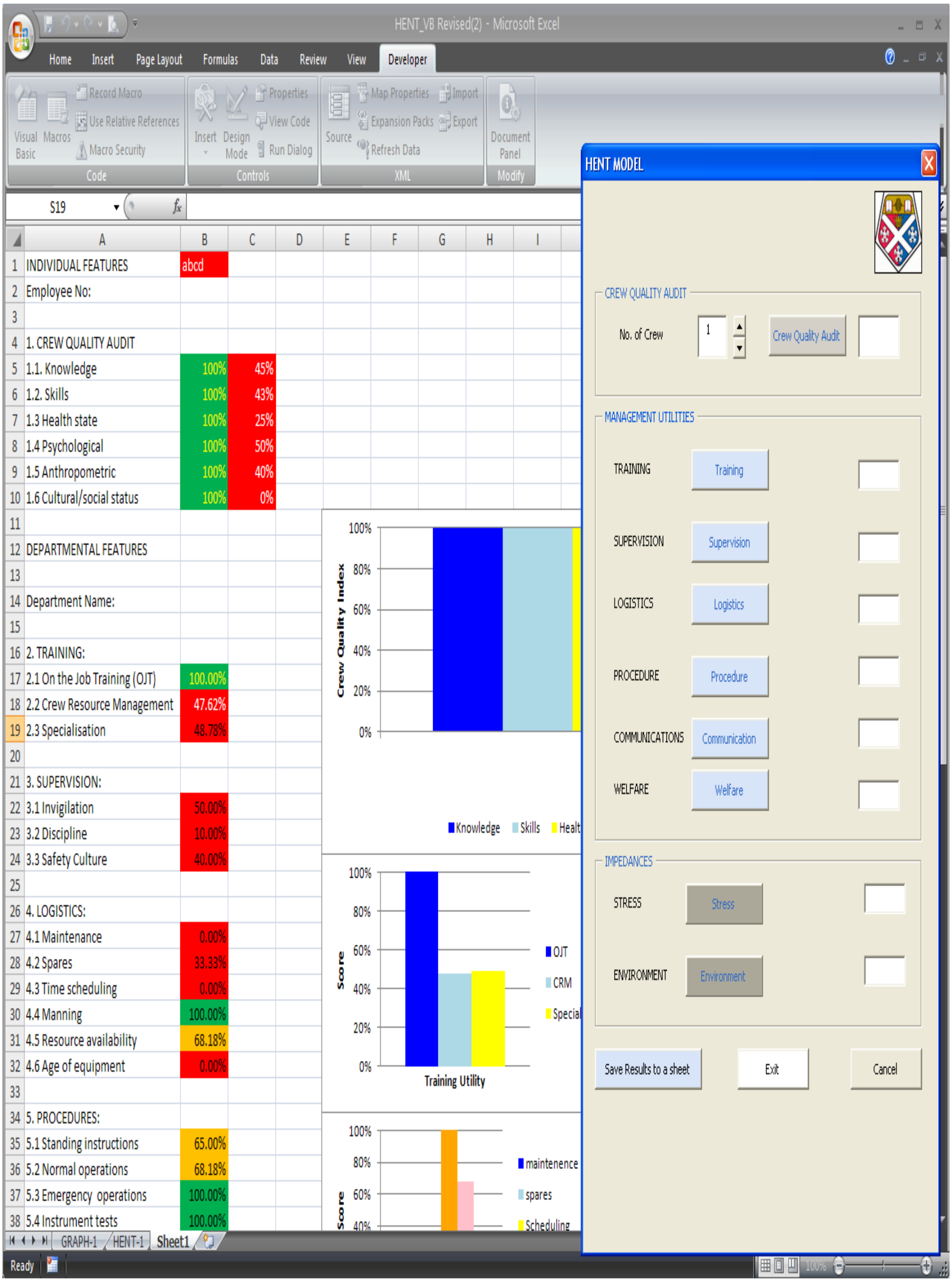
6) Documented account of operational conditions

7) Leverage extensive part libraries with re-run capability

8) Graphical print out of results with custom coloured indicators of risk zones

Furthermore, the HENT model allows the analyst to document results of a number of techniques and trials when carrying out overall analysis. Although the HENT software was developed based on maritime operational criticalities, it can be adopted by any industry with slight modification such as re-assessment of the environmental factors since not all conditions apply.

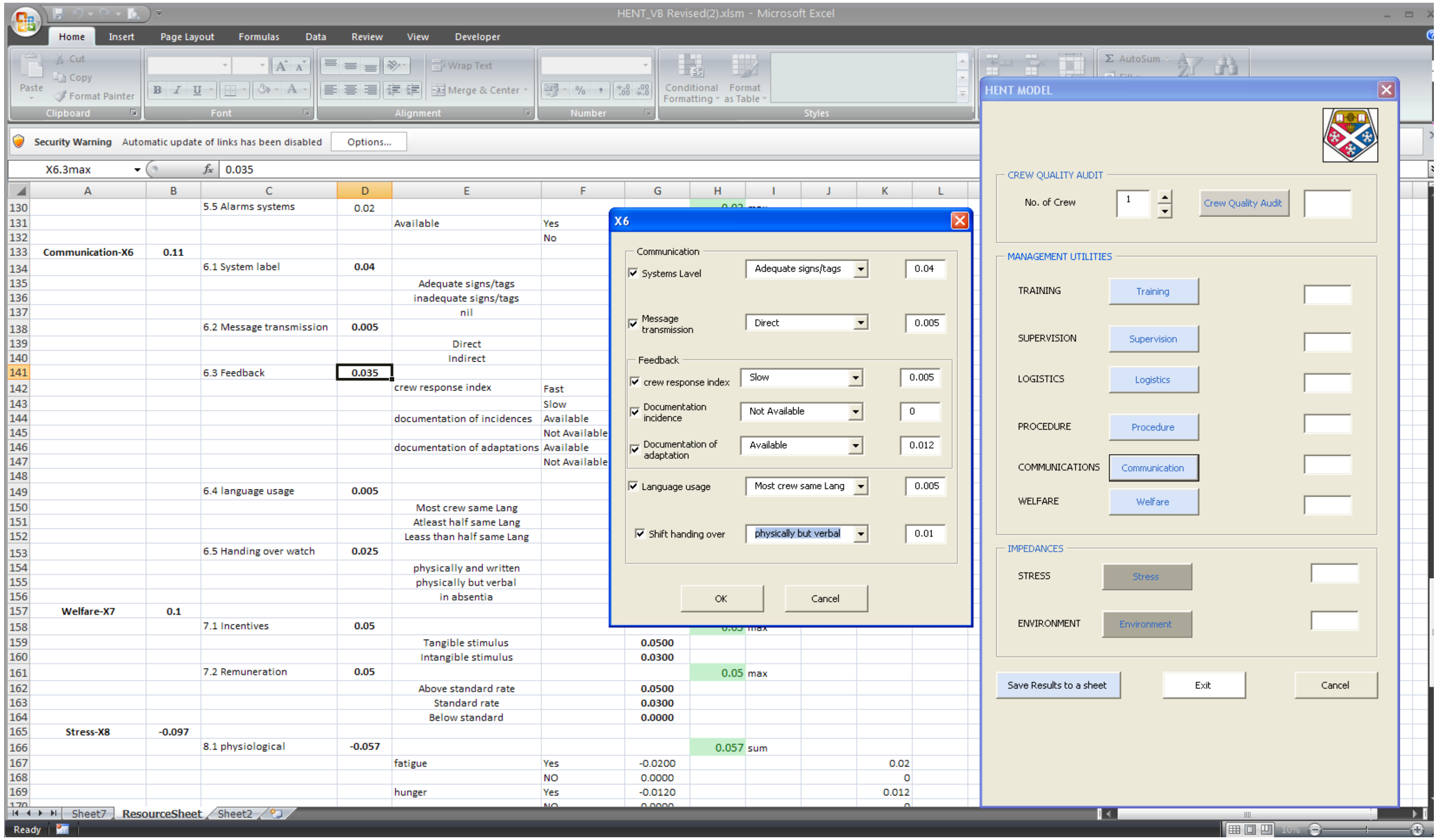
Figure 8:9 shows the front page layout of the HENT Model software with the pop-up window to the right. When any of the 9 human entropy boundary conditions is selected new windows pop up with all the variable construct utilities of the selected HEBC as Figure 8:9. Sample window pop ups for Communication (X6) and Logistics (X4) are shown in Figures (8-10) and (8-11) respectively. The green colours signify good practice while the red colours indicate high risk condition as shown in Table 8-3. The HENT software can as well, provide a powerful training tool for crew resource management because of its screening capability and level of details.



No. of Crew 1

	A	B	C
1	INDIVIDUAL FEATURES	abcd	
2	Employee No:		
3			
4	1. CREW QUALITY AUDIT		
5	1.1. Knowledge	100%	45%
6	1.2. Skills	100%	43%
7	1.3 Health state	100%	25%
8	1.4 Psychological	100%	50%
9	1.5 Anthropometric	100%	40%
10	1.6 Cultural/social status	100%	0%
11			
12	DEPARTMENTAL FEATURES		
13			
14	Department Name:		
15			
16	2. TRAINING:		
17	2.1 On the Job Training (OJT)	100.00%	
18	2.2 Crew Resource Management	47.62%	
19	2.3 Specialisation	48.78%	
20			
21	3. SUPERVISION:		
22	3.1 Invigilation	50.00%	
23	3.2 Discipline	10.00%	
24	3.3 Safety Culture	40.00%	
25			
26	4. LOGISTICS:		
27	4.1 Maintenance	0.00%	
28	4.2 Spares	33.33%	
29	4.3 Time scheduling	0.00%	
30	4.4 Manning	100.00%	
31	4.5 Resource availability	68.18%	
32	4.6 Age of equipment	0.00%	
33			
34	5. PROCEDURES:		
35	5.1 Standing instructions	65.00%	
36	5.2 Normal operations	68.18%	
37	5.3 Emergency operations	100.00%	
38	5.4 Instrument tests	100.00%	

Figure 8:9 - HENT Model Front Page Design



Security Warning Automatic update of links has been disabled

X6.3max 0.035

	A	B	C	D	E	F	G	H	I	K
130			5.5 Alarms systems	0.02						
131					Available	Yes				
132						No				
133	**Communication-X6**	**0.11**								
134			6.1 System label	**0.04**						
135					Adequate signs/tags					
136					inadequate signs/tags					
137					nil					
138			6.2 Message transmission	**0.005**						
139					Direct					
140					Indirect					
141			6.3 Feedback	**0.035**						
142					crew response index	Fast				
143						Slow				
144					documentation of incidences	Available				
145						Not Available				
146					documentation of adaptations	Available				
147						Not Available				
148										
149			6.4 language usage	**0.005**						
150					Most crew same Lang					
151					Atleast half same Lang					
152					Leass than half same Lang					
153			6.5 Handing over watch	**0.025**						
154					physically and written					
155					physically but verbal					
156					in absentia					
157	**Welfare-X7**	**0.1**								
158			7.1 Incentives	**0.05**						
159					Tangible stimulus		**0.0500**			
160					Intangible stimulus		**0.0300**			
161			7.2 Remuneration	**0.05**				0.05	max	
162					Above standard rate		**0.0500**			
163					Standard rate		**0.0300**			
164					Below standard		**0.0000**			
165	**Stress-X8**	**-0.097**								
166			8.1 physiological	**-0.057**				0.057	sum	
167					fatigue	Yes	-0.0200			0.02
168						NO	0.0000			0
169					hunger	Yes	-0.0120			0.012

X6

Communication

☑ Systems Lavel — Adequate signs/tags — 0.04

☑ Message transmission — Direct — 0.005

Feedback

☑ crew response index — Slow — 0.005

☑ Documentation incidence — Not Available — 0

☑ Documentation of adaptation — Available — 0.012

☑ Language usage — Most crew same Lang — 0.005

☑ Shift handing over — physically but verbal — 0.01

HENT MODEL

CREW QUALITY AUDIT

No. of Crew 1

MANAGEMENT UTILITIES

TRAINING

SUPERVISION

LOGISTICS

PROCEDURE

COMMUNICATIONS

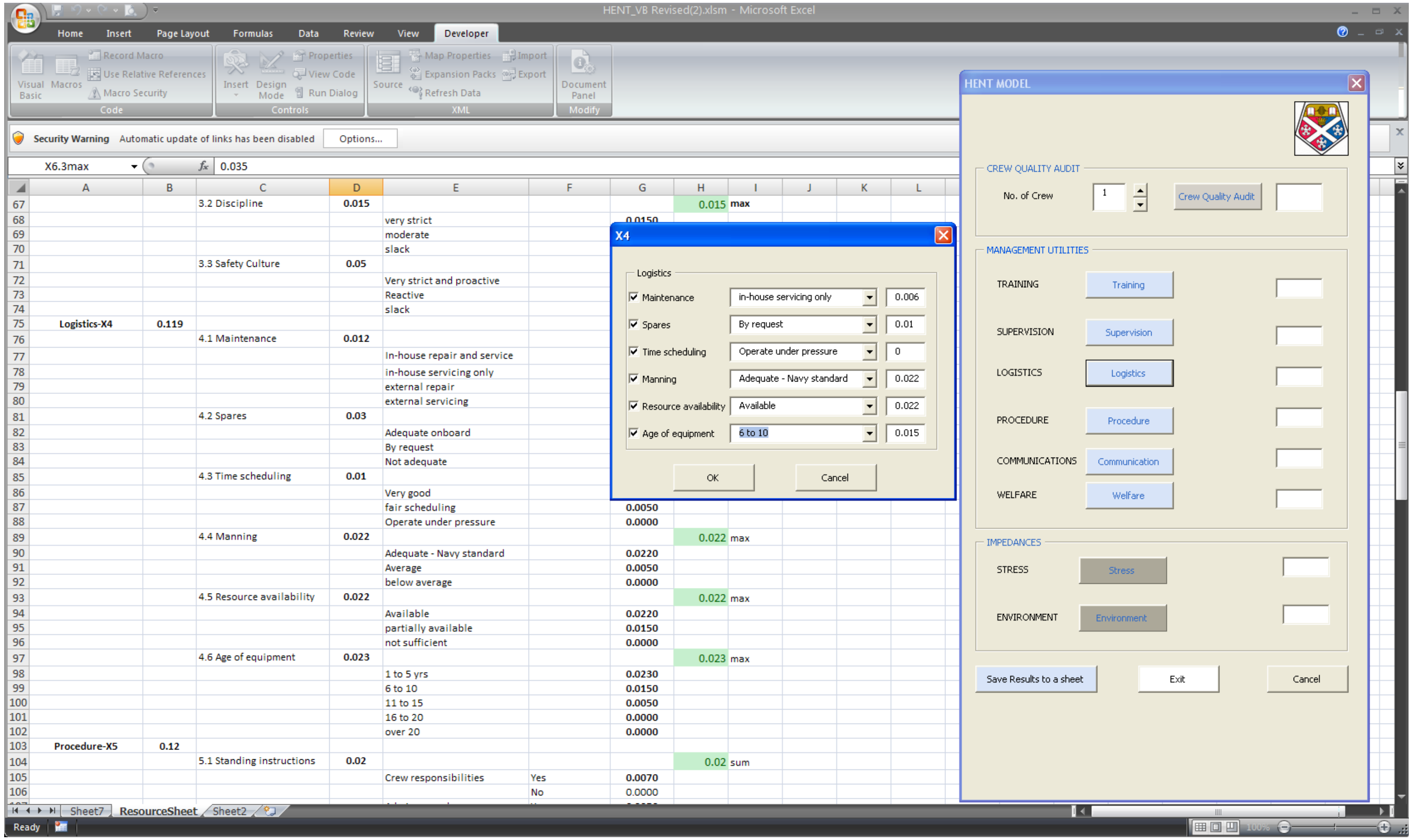
WELFARE

IMPEDANCES

STRESS

ENVIRONMENT

Figure 8:10 – HENT Window for Communication (X6)



X6.3max 0.035

	A	B	C	D	E	F	G	H	I
67			3.2 Discipline	0.015				0.015	max
68					very strict		0.0150		
69					moderate				
70					slack				
71			3.3 Safety Culture	0.05					
72					Very strict and proactive				
73					Reactive				
74					slack				
75	Logistics-X4	0.119							
76			4.1 Maintenance	0.012					
77					In-house repair and service				
78					in-house servicing only				
79					external repair				
80					external servicing				
81			4.2 Spares	0.03					
82					Adequate onboard				
83					By request				
84					Not adequate				
85			4.3 Time scheduling	0.01					
86					Very good				
87					fair scheduling		0.0050		
88					Operate under pressure		0.0000		
89			4.4 Manning	0.022				0.022	max
90					Adequate - Navy standard		0.0220		
91					Average		0.0050		
92					below average		0.0000		
93			4.5 Resource availability	0.022				0.022	max
94					Available		0.0220		
95					partially available		0.0150		
96					not sufficient		0.0000		
97			4.6 Age of equipment	0.023				0.023	max
98					1 to 5 yrs		0.0230		
99					6 to 10		0.0150		
100					11 to 15		0.0050		
101					16 to 20		0.0000		
102					over 20		0.0000		
103	Procedure-X5	0.12							
104			5.1 Standing instructions	0.02				0.02	sum
105					Crew responsibilities	Yes	0.0070		
106						No	0.0000		

X4

Logistics

☑ Maintenance	in-house servicing only	0.006
☑ Spares	By request	0.01
☑ Time scheduling	Operate under pressure	0
☑ Manning	Adequate - Navy standard	0.022
☑ Resource availability	Available	0.022
☑ Age of equipment	6 to 10	0.015

HENT MODEL

CREW QUALITY AUDIT

No. of Crew: 1

Figure 8:11- HENT Window for Logistics (X4)

Table 8-3: Definition for HENT Software Colour Code

HENT Model Colour Code	Description	Remarks
🟩	Very Good	A bench mark of 90 -100
🟩	Good	A bench mark of 71-89
🟥	Fair	A bench mark of 51 -70
🟧	Poor	A bench mark set at 50% and below

8.11 Design Concept of HENT

The concept of HENT has been extensively discussed and various equations with different applications have evolved. Table 8-4 provides a summary of all the equations derived, and their applications as demonst6rated in Figure 8:12 . The modelling concept and techniques shown in Figure 8:12 indicate how the HEBCs are run through the network to assess human factor in maritime operations. Leverage extensive part libraries with re-run capability and at every cycle, the boundary conditions can be changed to observe changes in the reliability

.

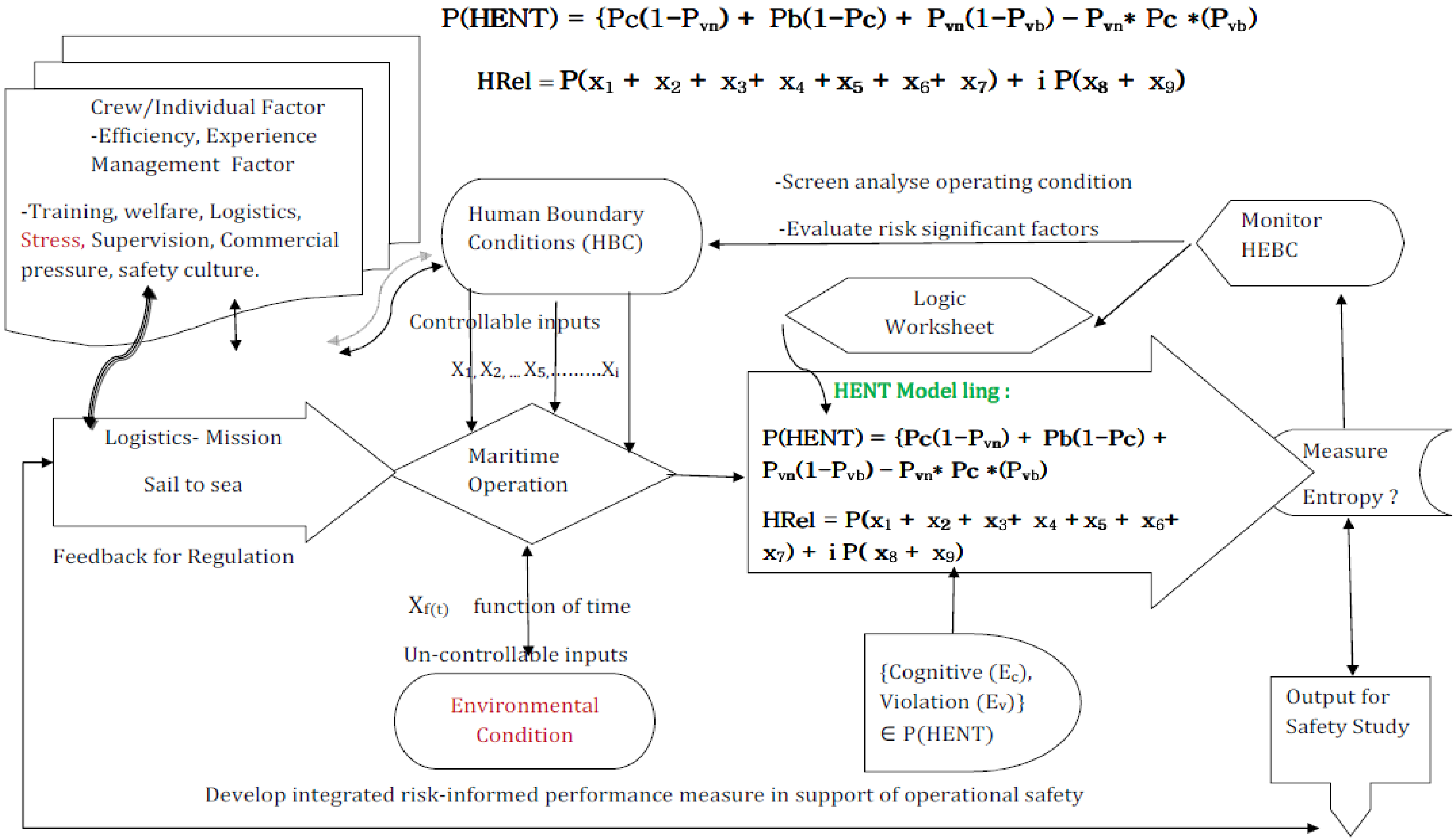


Figure 8:12- HENT Modelling Concept

Table 8-4 – Summary of HENT Modelling Utilities and Applications

Designation	Equation	Application	Remarks
HENT	$P(HENT) = \{P_c(1-P_{vn}) + P_b(1-P_c) + P_{vn}(1-P_{vb}) – (P_{vn})^* (P_c) ^*(P_{vb})$	This measures the human contribution to failures Known as human entropy.	This is based on the current values of the tripartite Failure modes.
THFM ($Ŧ_{\text{entropy}}$)	$Ŧ_{\text{entropy}} = f(e_c, e_{vn}, e_{vb}) = K \frac{1}{\sum_{i=1}^{7} P(Xi)}$	The K value can be used to predict each of the human failure modes	The K value of each industry varies according to historical data of the accidents/incidences within the organisation.
Management Factor ($f(Mgt)$)	$f(Mgt) = \sum_{n=2}^{8} P(X_i)$	Measures management contribution to failure	Since the management is responsible for Logistics, manning, crew welfare etc; these boundary conditions were used to determine how the management influence crew disorderliness.
Theoretical Human	$THRel = (x_1 + x_2 + x_3+ x_4 +x_5 + x_6+ x_7) + i\ (x_8$	Theoretical measure provides the human	The expression indicating what is measurable and controllable as real

Reliability (THRel)	$+ x_9)$	reliability ; real and fictitious utilities	and the imaginary as what is not measurable but can be strategically controlled
Practical Human Reliability (HRel)	$\text{HRel} = \frac{\{(x1 + x2 + x3 + x4 + x5 + x6 + x7) - \{(x8 + x9)\}}{(x1 + x2 + x3 + x4 + x5 + x6 + x7)}$	Provides unitary value of the HRA result	The HENT software was developed on the principle in this equation. However, from the software it is possible to measure crew quality index and management factor.

:

8.12 Concluding Remarks

The development of the HENT model offers another contribution to the ongoing effort to reduce the risk of accidents in the maritime industry. Failures are not solely due to cognitive errors; they may be due to the *legitimate* application of rationality or trade-offs. In addition to cognitive errors, other forms of human error have been identified in the form of negligence and breach. Failures due to negligence are dominant, and are as high as 60% compared to other human failure modes. The conditions that influenced human disorderliness have been established qualitatively in the form of hypothetical construct variables in a logic worksheet, which provides the input for the HENT analysis. The stressors are inevitable in maritime operations and unless technology eliminates the influences of the stressors, 99% human reliability is not attainable. It is therefore necessary to find a means which could improve and manage human and system resiliency to avoid errors. This can only be achieved by assessing operational realities to identify operational constraints which could trigger crew error bounded rationalities and extraneous acts. By identifying appropriate tools which could predict crew quality and management factors such as the HENT model, appropriate human and infrastructure can be placed to provide systemic resiliency to failure.

The HENT model provides all the tools necessary for conducting the human factors risk assessments required by stakeholders; regulatory agencies, insurance and management. The HENT modelling technique is partitioned into real and imaginary components with three fold quantification: human (crew), management, and stressor components. The premise for the use of imaginary and real parts is to provide greater latitude for the representation of mental and physical human failure modes that could facilitate mitigation. The HENT model was calibrated using literature reviews on the human contribution to failure, and worked examples have been demonstrated for the crew quality audit. Adjustments can be performed by the iteration of variables, and the concept design offers simple documentation and outright mitigation. Overall, as this is entirely a new concept, further study on the categorisation of the three components and associated utilities is highly recommended because no specific literature or theory was used to support the taxonomy.

CHAPTER 9.Case Study on Crew Quality Audit

9.1 Introduction

Following the development of Human Entropy Boundary Conditions (HEBC) as performance shaping factors, and subsequently the design of the Human Entropy (HENT) model for maritime operations, a case study was undertaken. The information contained was obtained from three different organisations and is treated with strict confidentiality. The case study is however, limited to Crew Quality Audit (CQA) because of lack of representative data. Most of the industries were not ready to release information due to confidentiality and possible fear of exposure to regulatory bodies.

The HENT modelling technique was designed as a tool to help organisations in the maritime sector to carry out qualitative and quantitative safety assessment on human system endeavour in operations. The model was developed in recognition of tripartite human failure modes in maritime operations. The human-system endeavour is therefore recognised and with good intention crew strive to maintain system persistence. As a consequence, crew may go through volitional acts which do not in any way include sabotage or intention to cause harm. Volitional acts manifest in the form of alterations and additions, corner cutting etc mainly due to scarce resources, work load or trying to improve efficiency. It is however in the course of the autonomy to use discretional ability that errors, negligence and breach take place. In the event of scarce resources ad hoc actions may be taken with or without mitigation of risk to restore operability and in some cases, with management consent to satisfy commercial pressure.

Nevertheless the maritime environment is characterised by quite a number of unpleasant situations which could cause and trigger chances for human disorderliness of any kind.

While at sea most crew members are subjected to various kinds of disturbances ranging from sleep disorderliness, boredom, task complexities etc; all of these were highlighted in the proceeding Chapters.

Therefore, in order to meet up with these challenges it is pertinent to have a competent, capable and reliable crew that could satisfactorily be deployed for maritime operations. The Crew Capability Audit (CCA) provides the requisite tool for measuring the Crew Capability Index (CCI) that can be used to determine crew risk factors. The risk factor or Crew Residual Risk (CRR) is a measure of crew member's ability, which should be evaluated and updated on a yearly basis.

9.2 Merits of the Crew Quality Index (CQI)

1. Identify high quality staff, and crew with high risk index (weak crew)
2. Help to delegate safety critical responsibilities
3. Guarantee crew resiliency in operations
4. Facilitate crew appraisals
5. Support crew development such as training requirements
6. Characterise organisational manning levels
7. Improve competitiveness' among crew
8. Create a datum for organisational documentation
9. Assign each crew with a CQI and maintain a record on Crew Residual Risk (CRR) which may be updated annually to monitor progression

Crew that exhibit a high reliability index can be relied upon to improve system efficiency and to handle safety critical operations. Similarly, the CCA will reveal areas of weaknesses to the organisation for manpower development and training.

In this exercise, a Crew Quality Audit (CCA) was conducted across three organisations within the maritime industry as follows:

1) A Shipping company based in Europe
2) An Oil company based in Europe
3) A Shipping company based in Africa

In all cases five (5) crew members were chosen at random for the CCA assessments. The Crew Quality Index (CQI) for each of the subjects was evaluated using CCA utilities from the HENT logic work sheet.

9.3 Aim of the Case Study

The aim of this study is to determine Crew Quality Index (CQI) using Hypothetical Construct variables (HyCs).

9.4 Objective of the Case Study

The Crew Quality Audit is a measure of crew vulnerability to error and could be used as a tool to identify gaps among staff in an organisation. CQA will be used to reveal weaknesses in crew and to provide guidelines on how to expunge the risk elements for potential manpower growth. Therefore, the specific objectives of this exercise are:

1) To demonstrate the capabilities of the HENT model

2) To identify learning outcomes for reliability analyses using the HENT tool

3) To compare crew quality between various organisations and identify crew limitations

4) To enhance conceptual and functional thinking by establishing the crew performance and functional demands for safe operability

5) To establish crew capability index and residual risks for organisational manpower development

9.5 Subjects

The subjects are crew members randomly drawn from three different maritime industries. In each case five (5) operating crew members were chosen at random and were screened directly by using the HENT modelling tool. Therefore, a total fifteen (15) crew were assessed.

9.6 Conduct of the Exercise

In the conduct of the exercise, a senior member of staff from each of the organisations was nominated to participate in the assessment. Assessors used organisational documentation and conducted brief interviews in order to gauge crew anthropometrics and communication echelon. The exercise was conducted with confidentiality in order to protect personnel records.

Assessors scored each crew based on information held on the crew and antecedents data under which knowledge on crew members were held. Scoring was done in accordance with laid down procedures using hypothetical constructs variables of the Human Entropy model as shown in Chapter 6, Table 7-3 (The logic worksheet) .

9.6.1.1 *Assumptions*

In this assessment the following assumptions were made:

1) The assessor knows the personnel (Physically or through their records)
2) Records of personnel appraisals were made available to the assessor
3) The personnel records are up to date and include:
    a) Medical records
    b) Presence at work
    c) Crew contributions to organisation
    d) Incidents /accidents records (social and professional) in which the crew was involved
    e) General status of crew records such as: marital status, education, work experience etc.

9.7 Results

Table 9-2 below provides the expert's assessment results for the CCA. The first column indicates the identity of one of the 15 crew members as an identification number (ID), as Crew $_{a\text{-}b.}$. The subscript subjects 'a' represent the company while 'b' indicates the number of the crew in company 'a'. For the fifteen member crew (15 member crews) we have Crew $_{1\text{-}1}$ through to Crew $_{3\text{-}5}$. The last column in Table 9-2 indicate the total score for each crew and it was observed that the highest and lowest values are 0.089 and 0.053 respectively.

A summary of results is shown in Table 9-3. The last column shows the evaluated Crew Quality Index (CQI) which is calculated as follows:

1) Maximum score for CCA as provided in Table 7:2 , Chapter 7 = 0.1337
2) In this exercise, the CCA (Total HyCs score) obtained for each crew member is provided in the last column of Table 9-2

Therefore Crew Quality Index (CQI) = (Sum of HyCs score) / (CCA)

CQI = (Sum of HyCs score) / (0.1337)

$$\text{CQI} = (\text{Sum of HyCs score}) * (7.48) \qquad (9{:}1)$$

{Note: the reciprocal of (0.1337) = 7.48}

By using equation (9:1), the values for each Crew Quality Index (CQI) were obtained as shown in the last column of Table 9-2. Results of the CQA shown in Table 9-2 were aggregated and summarised in Table 9-3.

9.7.1.1 ***Example:***

A worked example on how to calculate CRR is shown in Table 9-1:

Table 9-1 - Worked Example

Crew ID	Sum of HyC Variables (from Table 9-2)	CQI (From equation (9.1))	Crew Residual Risk (CRR) = 1 - CQI

Crew 1-1	0.089	(0.089) x (7.48) = 0.666	1- 0.666 = 0.334

Once the programme is set to run, the HENT software generate the results in different format; Spreadsheet, Table and a bar chart. Table 9-4 present a colourful output of results calculated from the HENT model software. The red colours indicate weak areas (high risk conditions) that are below acceptable limits. The essence of the colour print out is to provide a quick view of the safety situation for necessary action. In addition to these unique HENT model graphical outputs; a bar chart output is automatically generated on a separate sheet. Appendix 8-1 presents the bar chart for the case study on crew quality audit which also, displays results with colours and compares individual scores.

Table 9-2 - Result Sheet on Crew Quality Audit case study

Crew ID	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11	y12	y13	y14	y15	y16	y17	Total
Crew 1-1	0.012	0.01	0.002	0.005	0.002	0.004	0.006	0.012	0.004	0.002	0.004	0.004	0.002	0.005	0.005	0.005	0.005	0.089
Crew 1-2	0.01	0.01	0.005	0.005	0.001	0.004	0.003	0.012	0.004	0.004	0.004	0.002	0.002	0.005	0.005	0	0.005	0.081
Crew 1-3	0.01	0.01	0.005	0.005	0.002	0.002	0.003	0.012	0.004	0.002	0.002	0.004	0.002	0.005	0.0025	0	0.005	0.0755
Crew 1-4	0.012	0.01	0.002	0.005	0.002	0.004	0.003	0.006	0.004	0.004	0.004	0.004	0.002	0.005	0.0025	0	0.005	0.0745
Crew 1-5	0.012	0.01	0.002	0.005	0.001	0.002	0.003	0.012	0.004	0.004	0.004	0.004	0.002	0.005	0.005	0.005	0.005	0.085
Crew 2-1	0.01	0.007	0.005	0.005	0.001	0.004	0.006	0.012	0.002	0.004	0.002	0.002	0.002	0.001	0.001	0.01	0	0.074
Crew 2-2	0.006	0.004	0.0025	0.001	0.001	0.003	0.004	0.006	0.002	0.002	0.002	0.004	0.002	0.005	0.001	0.01	0.005	0.0605

Crew 2-3	0.006	0.004	0.0025	0.002	0.001	0.004	0.006	0.006	0.004	0.002	0.002	0.002	0.002	0.005	0.005	0.01	0	0.0635
Crew 2-4	0.006	0.005	0.003	0.002	0.001	0.003	0.006	0.006	0.002	0.004	0.002	0.002	0.002	0.005	0.005	0.01	0	0.064
Crew 2-5	0.01	0.005	0.003	0.005	0.001	0.002	0.004	0.006	0.002	0.004	0.002	0.002	0.002	0.001	0.005	0.01	0.005	0.069
Crew 3-1	0.012	0.005	0.004	0.003	0.002	0.003	0.003	0.006	0.003	0.004	0.003	0.004	0.003	0.003	0.003	0.01	0.01	0.081
Crew 3-2	0.01	0.01	0.002	0.001	0.001	0.002	0.006	0.006	0.004	0.004	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.074
Crew 3-3	0.006	0.01	0.002	0.001	0.002	0.006	0.006	0.004	0.004	0.002	0.004	0.004	0.003	0.004	0.004	0.005	0.005	0.072
Crew 3-4	0.01	0.01	0.002	0.001	0.002	0.002	0.006	0.006	0.006	0.004	0.003	0.004	0.002	0.004	0.004	0.002	0.002	0.07
Crew 3-5	0.005	0.005	0.004	0.003	0.002	0.003	0.002	0.003	0.003	0.006	0.003	0.003	0.003	0.004	0.004	0	0	0.053
Aggregated	0.137	0.115	0.046	0.049	0.022	0.048	0.067	0.115	0.052	0.052	0.044	0.048	0.035	0.061	0.056	0.082	0.057	1.086

Average	0.0091	0.0077	0.0031	0.0033	0.0015	0.0032	0.0045	0.0077	0.0035	0.0035	0.003	0.0032	0.00233	0.0041	0.00373	0.0055	0.0038	0.0724

Table 9-3 - Summary of Results on Crew Quality Audit

Crew ID	Education	Skills	Health	Psychological	Anthropometric	Culture & Social	CQI %
Crew 1-1	0.012	0.029	0.012	0.016	0.005	0.005	67
Crew 1-2	0.01	0.028	0.012	0.016	0	0.005	61
Crew 1-3	0.01	0.027	0.012	0.014	0	0.005	57
Crew 1-4	0.012	0.026	0.006	0.018	0	0.005	56
Crew 1-5	0.012	0.023	0.012	0.018	0.005	0.005	64
Crew 2-1	0.01	0.028	0.012	0.012	0.01	0	55
Crew 2-2	0.006	0.0155	0.006	0.012	0.01	0.005	45
Crew 2-3	0.006	0.0195	0.006	0.012	0.01	0	48.5
Crew 2-4	0.006	0.02	0.006	0.012	0.01	0	48
Crew 2-5	0.01	0.02	0.006	0.012	0.01	0.005	52
Crew 3-1	0.012	0.02	0.006	0.017	0.01	0.01	61

Crew 3-2	0.01	0.022	0.006	0.018	0.005	0.005	55
Crew 3-3	0.006	0.027	0.004	0.017	0.005	0.005	54
Crew 3-4	0.01	0.023	0.006	0.019	0.002	0.002	52.4
Crew 3-5	0.005	0.019	0.003	0.018	0	0	40

9.8 Discussion of Results

The objective and qualitative basis for the Crew Quality Index scale is to gauge crew ability and compare results which could be used as a guide to deployment. The outcome of the exercise and observations are as follows:

1) The Crew Quality Index provides a risk level for each individual and the overall risk index for the organisation can be obtained from the results shown in Table 9-2.
2) The results show significant correlation between crews as can be seen in Table 9-3. The standard mean errors are negligible except for Cultural and Social status between crews.
3) The best crew had a crew quality index of 0.67, and thus, a residual risk of 0.33.
4) The lowest value for the crew quality index was 0.4 and has a residual risk of 0.6. This indicates that the crew is weak in:
    a) Knowledge

    b) Health state

    c) Culture and level of sociability

    d) Anthropometric (this is further justified by their health status)

5) The overall results indicated a mean value of 54.3% for the CQA for the 15 crew members, who are also indicated in the last row of Table 9-2.

6) Though the 54.3 % mean CQA is seemingly low, this value does not indicate the human reliability measure which depends on eight (8) other factors of the HEBC. The CQA result is only an indicator to the crew status and since human development is continuous, the areas of weakness have been highlighted.

7) The crew with the lowest quality index may be a junior officer that has just joined the organisation and this is also indicated in their low score in Table 9-3, under experience.

8) Table 8-4, provides a pictorial view of the results and it shows the distribution of variables between crew members.

9.9 Learning Outcome

In this exercise, the software provides a qualitative tool for evaluating and measuring organisational risk vulnerability due to the quality of its workforce. Whilst there are varying personnel statuses such as experience, knowledge, demography, extraversion etc, the following learning outcomes and benefits of the model are outlined below.

9.9.1.1 *Alertness*

The assessment enables personnel to behave better and improve their cognitive alertness and overall efficiency. Indicators to this can be derived from the psychological and anthropometric variables.

9.9.1.2 *Individual Risks*

The CQI enables the organisation to identify gaps in each individual crew member. The gap can potentially reveal training requirements for the crew to enhance skills and knowledge e.g. Crew Resource Management Training.

9.9.1.3 *Deployability*

Since the Crew Quality Audit can reveal individual residual risk (reliability index), deployment of crew can be tailored commensurate to his/her status and where necessary, provision for closer supervision can be put in place.

9.9.1.4 *Documentation*

The CQA is also a tool which provides appraisal reports. The appraisal report for each of the crew members can be documented to monitor progression in reliability, and for advancement.

9.9.1.5 *Workforce Capability Audit*

Overall organisational manpower quality can be evaluated by aggregating individual results to obtain the crew reliability. Therefore, the workforce strengths and weaknesses in an organisation can be predicted.

9.10 Conclusion

A total of 15 subjects were sampled for this study from three different organisations within the maritime industry. The case study results show variation between crew qualities; the highest value obtained is 67% and with a lowest value of 40%. The average of the crew quality index for all the crew is 54.3%. The seemingly low average value is an indication that crew must be continuously developed and re-trained in an organisation. The HENT model offers a great opportunity for crew appraisals and deployability via the Crew Quality Audit. In building reliable human capacity, the CQA can be used as a tool to identify areas that require further improvement, and for crew selection criteria. In this exercise, the risk factor of individual crew was identified and could be used in crew deployment. By this study, the capability of the HENT model program proved to be a powerful tool for safety assessment. It is quite clear how the results are displayed in different formats and in a comparative manner shown in the Appendix. The modelling proved very fast, reliable and with excellent documentation capabilities. The HENT model software can be institutionalised by organisations as part of a policy to measure human risk in operation. Overall, the results show that capacity building must be a continuous exercise for development, and the assessment provides a tool to measure personnel risks

.Table 9-4- Sample print out result for case study on CQA on fifteen subjects

1. Crew Quality Audit	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C14	C-15
1.1. Knowledge	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	45.45 %	60.61 %
1.2. Skills	84.72 %	77.78 %	75.00 %	73.61 %	65.28 %	61.11 %	58.33 %	61.11 %	69.44 %	59.72 %	59.72 %	58.33 %	66.67 %	61.11 %	80.56 %
1.3 Health state	50.00 %	100.00 %	100.00 %	25.00 %	50.00 %	25.00 %	25.00 %	25.00 %	25.00 %	100.00 %	25.00 %	25.00 %	25.00 %	25.00 %	100.00 %
1.4 Psychological	80.00 %	80.00 %	70.00 %	90.00 %	90.00 %	60.00 %	60.00 %	60.00 %	60.00 %	60.00 %	90.00 %	100.00 %	90.00 %	90.00 %	90.00 %
1.5 Anthropometric	100.00 %	100.00 %	70.00 %	70.00 %	100.00 %	40.00 %	70.00 %	100.00 %	100.00 %	40.00 %	70.00 %	100.00 %	100.00 %	70.00 %	100.00 %
1.6 Cultural/social status	100.00 %	33.33 %	33.33 %	33.33 %	100.00 %	66.67 %	100.00 %	66.67 %	66.67 %	100.00 %	100.00 %	100.00 %	100.00 %	100.00 %	100.00 %
															0.0851

CHAPTER 10. General Discussions and Recommendations

10.1 General Remarks

Having discussed the Human Entropy (HENT) modelling techniques in the previous Chapters and which was accompanied by case study, this Chapter explains further some of the background principles and logic behind the concept. The HENT model outlines three main actors in human factors contribution to failure vis a vis: the human component, management bit and stressors. This segmentation is important and is designed to facilitate mitigation that could single out generic root cause of failures.

10.2 Uniqueness of HRA for Marine Operations

The challenge in human reliability analysis is in developing a high level model that is industry specific in its functions. The model must accommodate specific changes in operational boundary conditions to evaluate risk continuously. Maritime operations are unique with complex actors coupled in an uncertain environment. Unlike any other industry, the maritime environment has the following unique characteristics:

1. Marine systems are operated in an isolated environment where external assistance is not readily available.

2. Mobile or floating condition generates continuously unstable state to crew and platform.

3. Limited manpower and limited combined effort due to job designation - for example each crew is restricted to a particular part of the ship/vessel.

4. Space limitation especially within the machinery area.
5. Difficulty in control of vessel and other associated manoeuvrability constrains.
6. Multiple incidents can occur, which also generate fear of an aggravated situation.
7. Limited logistics such as emergency repair tools and spares, food stuff, fuel etc.
8. Complex system platform associated with design constraints.
9. Time criticality in response to mitigate emerging dangers.
10. Nature of problem at hand and type of cargo or mission.
11. Environmental threatening factors such as weather, capsize, grounding, collision, smoke and toxic substances.
12. Higher level of stress on crew due to workload, anxiety, sea state etc
13. Higher demand for instantaneous decision making and exhaustive use of initiatives

These and many more warrant selection of high quality crew with physical strength, sound health and high mental stability. Figure: 10-1 shows a pictorial situation with hazardous potentials which may prevail while in a voyage or operating any platform at sea.

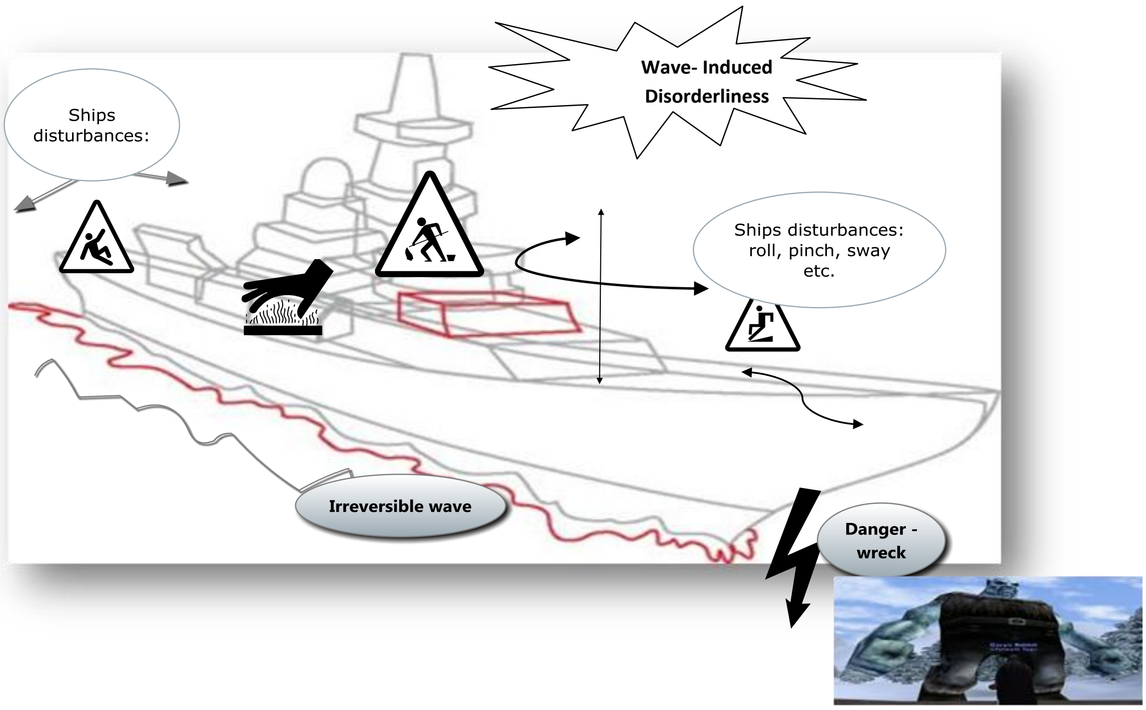


Figure: 10-1- Criticalities in Maritime Operations

The manifestation of human failure must not be seen as synonymous to equipment failure to carry out its design function since the error may be refuted by design interlocks or failsafe devices. The main issue should be; what and how the operator did contribute to the failure or even accident in interacting with the system? In the case of operator bounded rationality (breach), even the failsafe devices may be bypassed for some reason to satisfy operational demand. Similarly, in the case of extraneous acts (negligence), the operator may simply ignore an alarm or respond to system's demand at his/her own time with disdain. Progression of human action in operations can therefore be viewed within an allotted space and time to accomplish a task. At sea, crewmembers must strive in all respects to maintain system continuity or ensure safe operability and act in a timely manner. In so doing, the crew encounters many challenges requiring discretionary action. Therefore, manifestation of human failure is only a function of time and space as shown in Figure: 10-2.

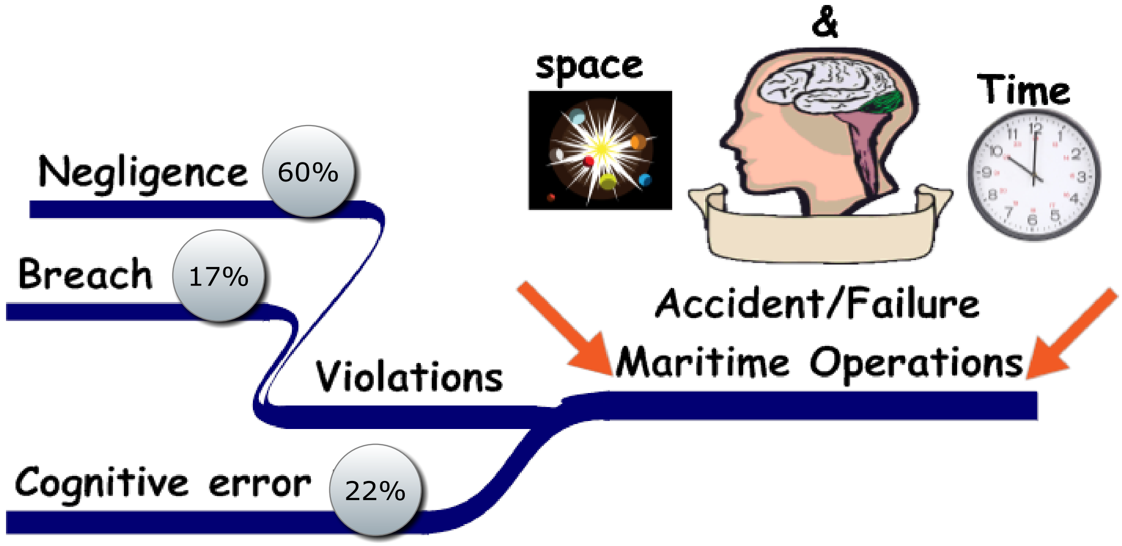


Figure: 10-2 – Crew proneness to tripartite failure modes

The design of HENT model is developed such that it permits iteration of variables from the root cause within human entropy boundary conditions utilities. By screening through the utilities, preventive action can be taken gauging from the output of quantification as simulated in Figure: 10-3. The current HRA uses '*lumped parameter analysis*', which generates a unitary value called the human error probability or reliability. The conceptualisation of this value is vague because all the three components listed above are combined to generate a unitary value. This value does not provide information that could be used to list the circumstances under which failure occurred. In HENT model, the human behaviour is simplified by addressing divergent behaviour and trends of causal factors. The use of a unitary value, as in current practice, prevents the identification of different problems. Thus, determining the cause and isolating the risk element has been very difficult. For instance, a reference to 60% human reliability does not provide any information beyond the corresponding 40% unreliability. The purpose of quantifying the human factor is to create a safety audit that can provide clue on how to eliminate or mitigates risk, but a unitary reliability value does not contain any information to aid in the creation of such an audit. Instead, the human reliability must be quantified by considering all three components of the human element, allowing the unreliability factors to be decoded through the quantitative taxonomy in which failure manifests, thus; Crew Component, Management part and Stressors must be isolated. This initiative will give greater latitude for iteration: increased control over controllable elements and a device strategy to manage the uncontrollable elements using resilience mechanisms. These uncontrollable elements are the stressors which are declared as 'imaginary'.

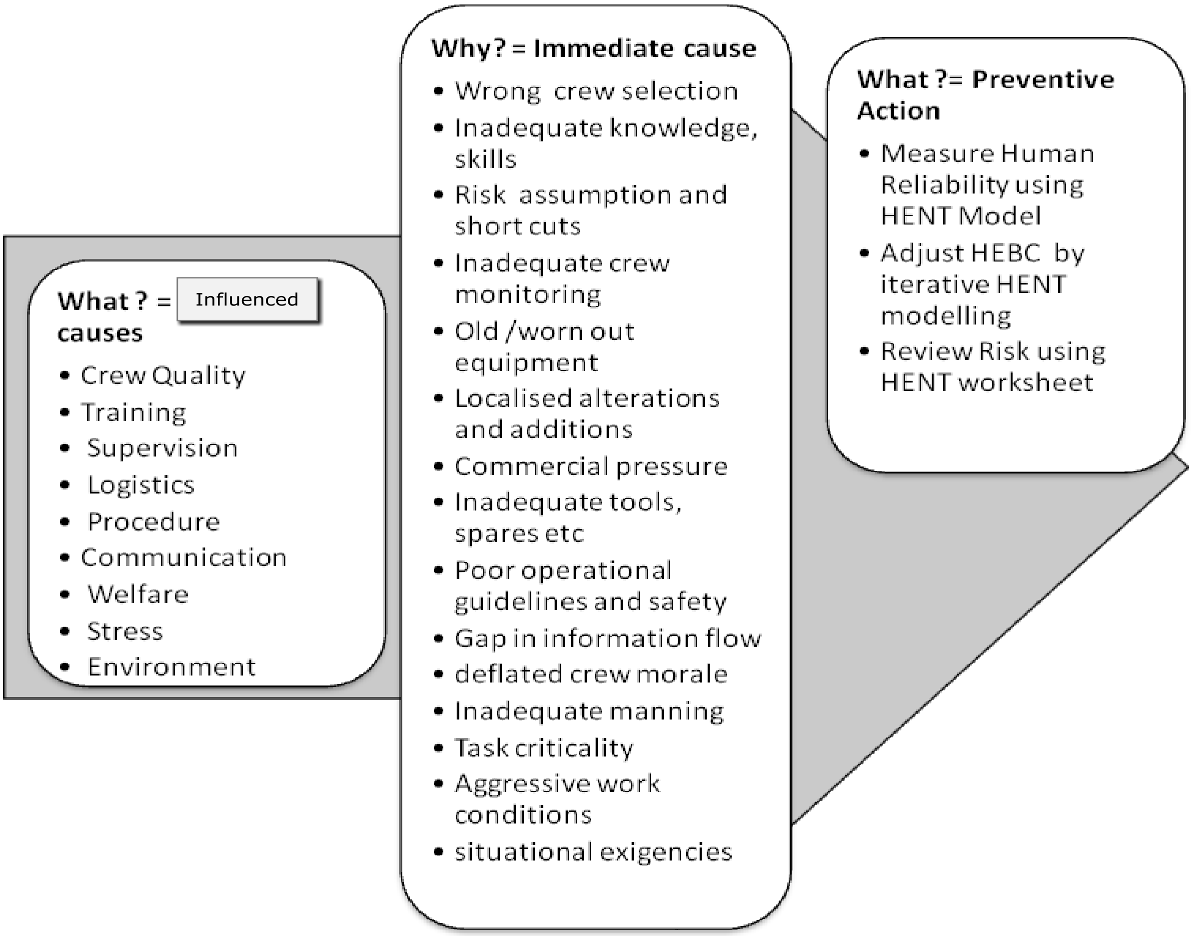


Figure: 10-3 - Road Map to HENT Analyses

10.3 The stressors - Imaginary Utilities

A controversial subject is hereby revisited; the negative probability. However, the objective is to combine our experiences to develop a logical mechanism that can predict the probability of human disorderliness (Marlow 1992; Tversky and Kahneman 1992; Haug 2004; Pykacz1 2006). The concept of negative probability has suffered many criticisms; nevertheless, it has been successfully used in finance and science. In engineering, complex numbers were introduced to accommodate inferences; subsequently, chaotic theory and fuzzy logic evolved. These later developments evolved because real-world situations are not deterministic, creating a need to qualify uncertainties in mathematical models (Michael Berry 2003; Werndl C 2009).

The hypothetical construct variables with negative signs are called *impedances* because they are constraints to human performances, akin to the impedance of an electric current. The impedances create an unpleasant environment and threaten the operator’s ability to perform, increasing the frequency of volitional acts and susceptibility to error. The sea state refers to the turbulence effect due to wave action, which continuously creates an unstable equilibrium for the crew and systems. The higher the stressor probability, the more unpleasant the conditions are for the crew, increasing the probability of committing an error. Considering the relationship between the stressors, equation 1:1 indicates that X_8 (work-induced stress) and X_9 (sea state) are not mutually exclusive. Therefore, with time, the sea state will exacerbate work stress in the crew.

$$X_8 \cap X_9 \neq \emptyset: \qquad (10:1)$$

The boundary conditions X_8 and X_9 are predictable only to a certain degree and become more complex with time. Therefore, human cognition cannot be deterministic because the effect of the stressors on crew is not easily measurable. These conditions were viewed as a special case for maritime operations. The subjective questionnaire used to determine pattern of sailor stress in maritime environment is shown in Appendix 10-1.

Therefore, Figure: 10-4 and Figure: 10-5 show work stress and sea-induced stress patterns, respectively, measured for the crew. The abscissa represents time in hours at sea, with the measurement initiated 20 hours before the vessel was launched, whereas the ordinate represents the crew's stress. It was assumed that the vessel operated under normal service conditions without any issues that increased the stress level beyond normal throughout the voyage. The cumulative stresses on the crew, derived from Figure: 10-4 and Figure: 10-5 are shown in Figure: 10-6.

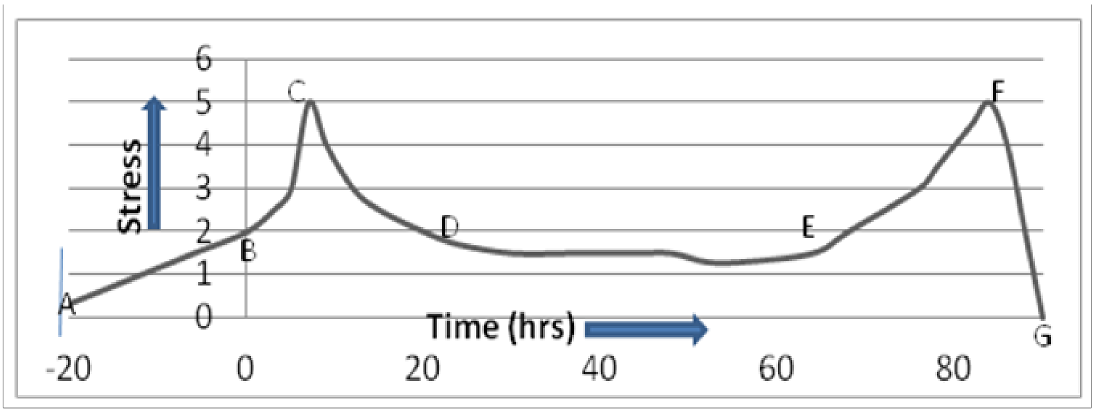


Figure: 10-4 - Work-Induced Stress on the Crew

10.3.1.1 ***Work-Induced Stress - Results in Figure: 10-4***

1) Points A to B show the induced stress on the crew within 20 hours of sailing. This form of stress is psychological and physical as a result of the preparations

for going to sea. This result shows that crews had residual stresses even before the vessel is put to sea.

2) Points B to C indicated a sharp increase in stress while leaving the harbour. At this point, all hands are on deck, striving to safely navigate the channel, which is characterised by heavy traffic and shallow, narrow passages.

3) Points C to D indicated a gradual reduction in stress in open seas. Although the sea effect on the crew may have increased as the vessel breaks through to the open sea C, approximately two-thirds of the crewmembers may go off watch. Similarly, the fact that the vessel is now out of the channel is a morale booster and a psychological relief for most crewmembers.

4) Points D to E indicated relative stability because the crew body systems adjusted to the sea conditions and they have performed two or three rounds of watch

5) Points E to F show a sharp increase in stress levels while entering the harbour, mirroring points B to C

6) Points F to G show a sharp decline in stress once the vessel is secured in the port of call. This stress reduction may not apply to all crewmembers; for example, some crew has to work extra hours to discharge Ro-Ro vessels and bulk carriers.

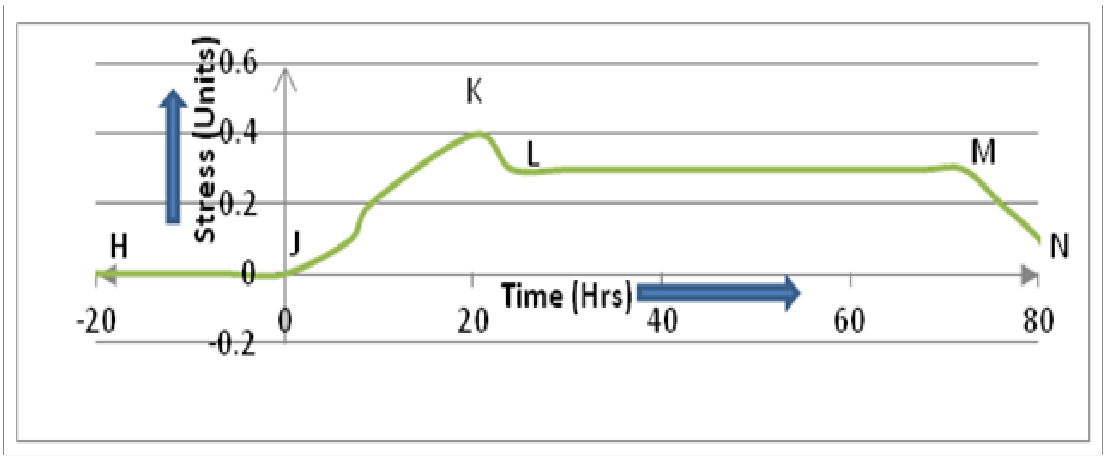


Figure: 10-5 - Sea-Induced Stress on the Crew

10.3.1.2 ***Sea-Induced Stress - Results in Figure: 10-5***

The curve in Figure: 10-5 shows the sea-induced stress on the crew, observing a similar pattern to the work stress in Figure: 10-4. However, from point L, the stress remains constant until the vessel is berthed at point M. This berth, however, does not exclude the possibility of turbulence at the jetty due to rough weather.

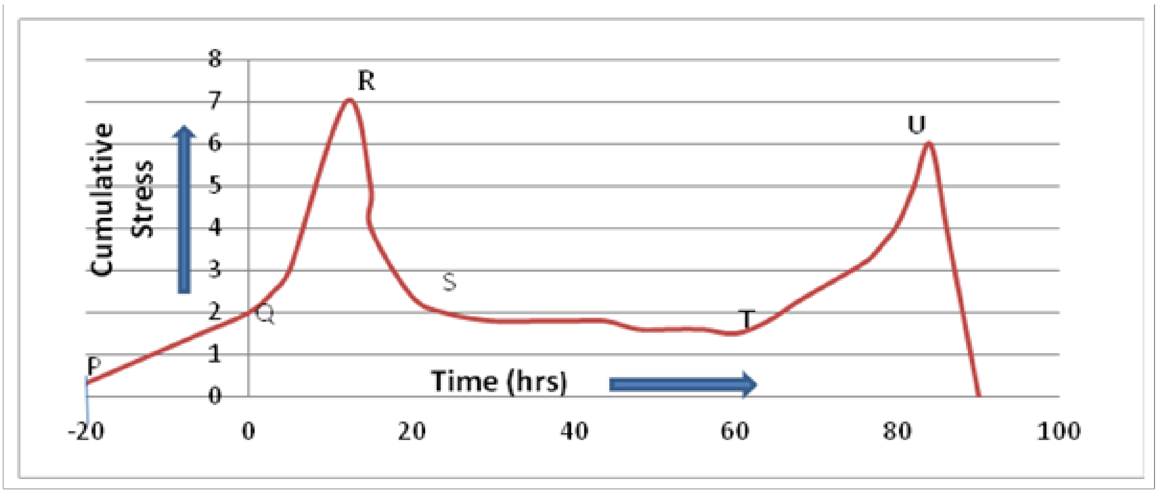


Figure: 10-6 - Cumulative Stress on the Crew

10.3.1.3 *Cumulative Stress - Results in Figure: 10-6*

The curve in Figure: 10-6 shows the cumulative stress level in the crew due to workload and the sea state. The resultant pattern does not follow any arithmetic summation law; rather, the cumulative result is a function of human body resiliency, which usually changes with experience of personnel. Using these inferences, the stress pattern at sea shows that:

$$X_8 \cap X_9 \neq \emptyset \qquad (10:2)$$

Therefore, taking the probability **P,**

$$P(X_8 \cup X_9) = P(X_8) + P(X_9) - P(X_8 \cap X_9) \qquad (10:3)$$

$$P(X_8 \cap X_9) = P(X_8)*(X_9) \qquad (10:4)$$

$$P(X_8 \cap X_9) = P(X_8)*P(X_8 | X_9) \qquad (10:5)$$

While X_8 has no effect on X_9, it was assumed that $P(X_8 \cap X_9)$ is negligible (due to the human body resiliency factor). The approximation is:

$$P(X_8 \cup X_9) = P(X_8) + P(X_9) \qquad (10:6)$$

The stressors generate *loss of energy* and have a periodic function. The periodicity in the stress pattern is generated as a function of watch/shift pattern onboard. Stress increases while the crew is on watch, and is released while off watch (relaxation period). The steady and unsteady state of the weather conditions (sea state) creates a chaotic state within human entropy boundary conditions that affects the crew: anthropometrics and psychological, communication, manning, unprecedented alarms etc. Thus, the representation of stress in quantitative terms has not yielded any positive results. A recent study performed by psychologists to assess over 25 stress-measuring procedures produced the following recommendation: '*there is a need for a fundamental* *rethink of the way in which stress is measured at work and how more valid and reliable tools for assessing stress can be developed'* (HRM 2002). Various studies have reported how stress and fatigue affect crew performance in the maritime domain (Raby and Mccallum 1997; Parker, et al. 2002; Hetherington, et al. 2006).

10.4 HENT Model – Application as Training Tool

The purpose of probabilistic risk analysis for the human factor is to create a safety audit which could be used to mitigate and eliminate potentials for risk due to human endeavour. At sea, insinuations to deal with problems on an ad-hoc basis are sufficient precursors for human disorderliness and perhaps accompanied by all acts of breach. The richness of HENT modelling technique can be applied to train ships personnel, management staff, regulatory bodies and other maritime stakeholders to achieve the following as follows objectives:

1) Create awareness on the tripartite human failure modes in operation and generic causes of each human failure mode. This will in turn widen trainee horizon on the need to increase vigilance and develop resiliency to adapt to disturbances.

2) To provide safety assessment and risk predictions based on prevailing operational exigency. This can be achieved through the screening processes in the logic work sheet. Operational constrains can be identified and mitigated in good time.

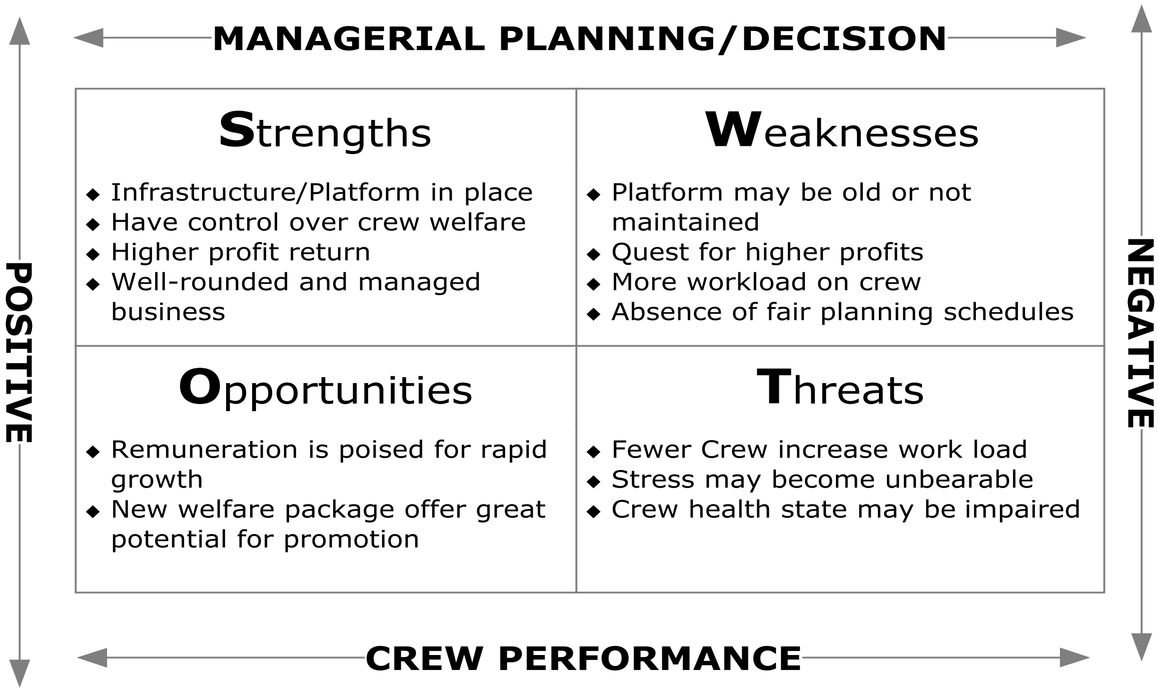
3) The assessments of crew quality using the crew capability audit can encourage competitiveness among crew. Each individual crew risk index can be developed on a data base to monitor crew progression. The Crew risk index can also assist

the management in decision making such as in: promotion, deployment or assigning of responsibility.

4) The HENT model support re-run under various operational conditions and the results are editable for comparative analysis. This will also help trainees to compare results and to understand how the human entropy boundary conditions can improve or reduce risk of failure.

5) The management contributions to crew disorderliness can be evaluated using the management boundary condition utilities e.g. provision of logistics, crew welfare etc, Management are the source of most human disorderliness because they are responsible for planning and decision making and which can go awry if enough precautions are not taken to the possible consequences and long-term repercussions. For instance; while profiteering is the focus, crew workload is likely to increase. Therefore, Managerial strengths is a function of availability of platform, high turnover etc. The strengths are also opportunities to crew and can be seen as commensurate to boost in welfare packages. Conversely, if the platform is old and worn out, the threat to safety will increase such as ; increased workload, impairments of crew health state etc. These scenario are demonstrated in Figure: 10-7

6) Therefore, regulatory agencies can have a framework for accident causation analysis and use HENT tool to fish out root causes of failure which may have occurred either due to: management factor, crew endeavour or due to environmental influence.



Strengths	**Weaknesses**
◆ Infrastructure/Platform in place ◆ Have control over crew welfare ◆ Higher profit return ◆ Well-rounded and managed business	◆ Platform may be old or not maintained ◆ Quest for higher profits ◆ More workload on crew ◆ Absence of fair planning schedules
Opportunities	**Threats**
◆ Remuneration is poised for rapid growth ◆ New welfare package offer great potential for promotion	◆ Fewer Crew increase work load ◆ Stress may become unbearable ◆ Crew health state may be impaired

Figure: 10-7- Effects of Management decision on safety

The logic worksheet has been designed top-down in order of good practice and requirement for safe operability. Operational constrains were allocated negative sign to indicate level of risk of the chosen variable. Therefore, for training application, trainees can run through the logic worksheet of the human entropy boundary conditions and develop the following hazard perception capabilities. The training will create an interactive session during which trainees shall be exposed to operational hazards in a work place and need to develop resilience and team collaboration.

Table 10-1- Advantages of HENT Model as Training Tool

HEBC	**Learning Outcome**	**Remarks**
Crew Quality Audit	✓ How to evaluate individual reliability and risk indexes (CQI) ✓ what constitute operators capability to perform various task functions ✓ Evaluation of crew health state to withstand environmental conditions	Promote competitiveness and provides management with appraisal tool. Since workload is a function of task risk, the physiological and cognitive limits of crew can be evaluated.
Training	✓ Personnel training needs for development ✓ Importance of type training such as Crew Resource Management (CRM) and how it improve CQI	Identifies and distinguishes novice and experience crew
Supervision	✓ What constitute supervision and monitoring ✓ Risks associated with non or inadequate supervision ✓ Work place discipline ✓ Vigilance	Trainees will appreciate the impact of monitoring and work place discipline

Logistics	✓ Risk in equipment depreciation and need for increased vigilance for old systems ✓ Need for strategic logistical items at sea and how it affects human reliability ✓ What standard manning should look and effects on crew ✓ What is the effect of manning on crew ✓ How management planning affects operational reliability	Logistics include the whole operational state of the system and its requirements to perform design function. This includes personnel requirement to sustain system persistence with all necessary tools and spares.
Procedure	✓ what equipment characteristics critical for crew not adequately defined ✓ Reliability Performance standards	Learn how procedural change and communication is a vital key to safety
Communication	✓ What constrains does crew imposed on the equipment? ✓ What are the critical operational standing orders ✓ Human-human, human-machine and machine – machine (noise, clarity, language)	A problem that stays with who ever discovered it is a problem that will ever remain unknown. Trainees will be made to realise the implications of gap in

	✓ \learn the importance of reporting any discovered problem among everyone	communicating observations and incidences. Piper Alpha mishap is the result inadequate work place communication.
Welfare	✓ What are the effects of remunerations on crew? ✓ How does welfare/incentive affect out? ✓ What influences relationship between crew and management	Trainees will understand effect of personal and work place welfare on safety.
Work stress	✓ Understand how stress is related to planning ✓ How manning influence stress growth in crew ✓ Effects of stress on crew performance	Scenarios on how stress manifest in crew were discussed and exploited in this Chapter. This part will caution crew and inform managers on how stress build up before, during and after voyage e.g. the MS Estonia mishap. Hence, consequences of haphazard planning will also be conceptualised by using HENT

		model.
Environment	✓ How does sea condition affect crew performance ✓ How system react due to wave effect and risks of alterations and additions in harsh weather ✓ Exploit the risks due to lack of good planning/scheduling of voyage against rough seas	Understand the risks posed by: noise, vibration, motion sickness, isolation etc. Trainees learn to develop resiliency and high crew quality index to succeed. Simulations can be run to compare results under various sea conditions.

By this design crew will be enlightened on the appropriate improvement which can be achieved by understanding the demands that problem solving may impose upon operational success. Similarly, the errors which crew may be prone to make in bounded rationality. The current HRA uses '*lumped parameter analysis*', which generates a unitary value called the human error probability or reliability. The conceptualisation of this value is vague because all the three components listed above are combined. This value does not furnish information that could be used to list the circumstances under which failure occurred. Human behaviour is thereby simplified by addressing divergent behaviour and trends of causal factors. The use of a unitary value, as in current practice, prevents the identification of different problems. Thus, determining the cause and isolating the risk element has been very difficult. For instance, a reference to 60% human reliability does not provide any information beyond the corresponding 40% unreliability. The purpose of quantifying the human factor is to create a safety audit that eliminates or mitigates risk, but a unitary reliability value does not contain any information to aid in the creation of such an audit.

Instead, the human reliability must be quantified by considering all three components of the human element, allowing the unreliability factors to be decoded through the quantitative taxonomy in which failure manifests. We therefore digress from conventional practices, extending the research and enriching the HRA paradigm. We strongly denounced the concept of a representative unitary value by proposing a partition between real (measurable) and complex (imaginary) components. This initiative will give greater latitude for iteration: increased control over controllable elements and a device strategy to manage the uncontrollable elements using resilience mechanisms.

10.5 HENT Model – Merits and Demerits

Various HRA techniques have been advanced and as pointed out in the critical review, Chapter 2, each HRA technique has its merits and demerits. One major obstacle in the progression of HRA models is lack of representative data and each industry has its characteristic requirements. Currently, the mandate required for a HRA model is to provide a practical-based predicting tool on potential risks and capabilities to succeed. And since, all humans err, the capability requirement is conceptual and functional thinking that could lead to resiliency.

Resilience engineering looks for ways to enhance the ability of organizations to create processes that are robust yet flexible, to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures. In the concept of resiliency, accidents are not just a result of breakdown or malfunctioning of systems under normal circumstances, rather; denote converse of adaptations necessary to sustain system persistence. And because, time and resources are limited, Individuals and organizations are deemed to develop resiliency to adjust their performance to the efficiency, thoroughness trade-off as (ETTO) as at when required. HENT model was developed on the basis that: Success is and attribute of ability of Crew and organisations to anticipate the operational risks before damage occurs and can be achieved vide quantitative hypothetical construct variables. With HENT model, we learn, respond, monitor and anticipate as demonstrated in Figure1-8.

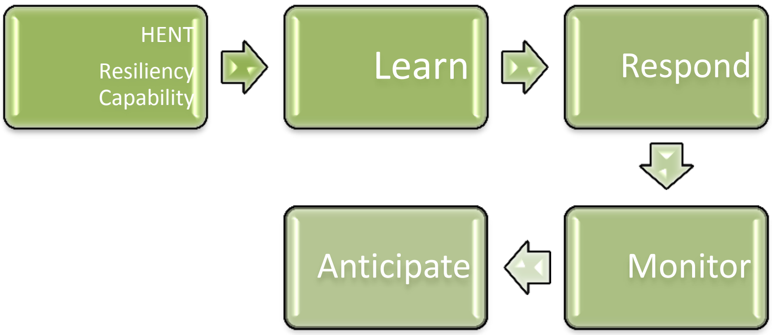


Figure 10:1- HENT Model Resiliency Concept

If demand exceeds the basic adaptive capacity, (for instance, in an emergency and rough sea conditions) there will be work interruption accompanied by reduce system performance. Suitable interventions can prevent decreasing system performance and return it to baseline performance. We can learn from the safety assessment of HENT model and respond by suitable interventions, such as: by employing crew with high quality index, increased welfare and logistics etc, and the system will return to baseline performance thus, exhibiting resilient performance. In most cases, minor things go wrong, little mistakes are made or corners are cut with deliberate adjustments; and if the corner is not kept smooth, weak crew may take advantage without considering the risk. Therefore, even while accidents are all too often blamed on human in-attentiveness or disorderliness, more often than not they are indicative of deeper and more complex of significant number of competing risks. Failure is a result of human-incompatibility to prevailing circumstances' in operations. The human must be designed robustly (as provided by HENT variables) to adapt to marine systems and environment. And in parallel, the platform must be design to adapt to the operators' needs and requirements (as detailed in the utilities of HEBCs).

Table 10-2 shows comparative analysis on various hazard analyses techniques based on different competing criteria (Arslan and Deha 2008) in which . HENT model, which shows good analytic functionality was inserted into Table 10-2 to evaluate its capability with other risk analysis techniques.

Table 10-2 - Modified Hazard Analysis Methods evaluation Table courtesy; (Arslan and Deha 2008)

	SWOT	**SWOT-AHP**	**HAZOP**	**What/if**	**FMEA**	**FTA**	**ETA**	**HENT Model**
Compatibility for multiple events/process analysis	Yes	Yes	No	Yes	No	No	No	Support scenario driven process analysis depicting operational status
Compatibility for single event/error analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	HENT is proactive , not reactive and can be used to identify gaps in safety
Taking into account	Yes	Yes	No	No	No	No	No	Environmental factors

external factors (positive/negative)								integrated in analysis
Taking into account internal factors (positive/negative)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compatibility for real-life application	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Needs brain storming/team work	No	No	Yes	Yes	Yes	No	No	Yes
Needs expert contribution	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Availability of manage	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Management factors

ment–operation intersection								clearly defined
Quantitative analysis	No	Yes	No	No	Yes	Yes	Yes	Yes
Qualitative analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Considers previous data/events	Yes	Yes	No	No	No	Yes	No	The HYCs evolved from expert experience and previous data
Considers expectation on data/events	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Checklist compatibility for	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

end-users								
Compatibility for on-the job training	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Suggests risk mitigation actions and produces strategies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Includes human factor	Yes	Yes	No	No	No	Yes	No	Yes

One of the major advantages of HENT model is that it provide quantitative output which can serve as a control parameter to measure and compare state of readiness. Therefore, Boundaries for running cautious operations can be revealed visible to organisation can be revealed to understand vulnerability. Ship operation is complex and occurrence of accident is not by mere shear of interest rather, accidents happen by the confluence discrete unsafe from; crew, management, system or environmental factors. For instance, voyage planning/scheduling is an important logistical utility which falls within the management factor, and if not mitigated can lead to devastating accident. Stress curves were used to demonstrate how management can influence stress escalation on sailors, and with HENT modelling utilities, management factors can be computed. Another factor which contributes to maritime accidents is inadequate knowledge of systems and operations. HENT model is also a powerful tool for seafarer training; the tool can be used to boost crew cognitive alertness and widen their vision on the need to be resilient to failure. The HENT model worthiness for seafarer training has been highlighted and by using HENT software, operational risks can be simulated under different conditions.

10.6 Recommendations for Future Studies

The present work has exploited the human failure modes and demonstrated how human factors trounce safety mechanisms in operations. A practical based human reliability analysis model called HENT, for maritime application, has been developed and designed. As this research work focuses on the human factor in maritime operations, recommendations for future work is hereby based on the original research questions. Therefore, the recommendations will be a follow up to complement the work done in this study and cover for gaps which could not be handled due to scope and time as follows:

10.6.1.1 ***Need for a Database***

The need to develop a database on human factors cannot be overemphasised. The databases on human factors must be composed such that:

1. The information content is plant/industry specific and therefore for better appreciation of local rationalities within such industry.

2. Data on human error should be used only for training, design improvement and must not be used as primary source for HRA. This is because as design and training improves, the data becomes obsolete since the same error may not be repeated and different individuals have different failure modes.

3. Data on human error need to be clearly defined and categorised such that specific possible human failure modes are made available and recorded as provided in

4.

5. Table 10-3.

Table 10-3 Proposed Template for Recording of Accident Data

Human Factors Component	Primary root cause	Secondary root cause	Complacency	Expert opinion on root cause	Remarks
Management Factor					
Personnel (Crew) Factor					
Environment					
Others					

10.6.1.2 ***Management Factors***

This should include failures which occur due to management interferences, negligence in maintenance, logistics, lack of risk-based voyage planning, over usage of limited number of crew, etc.

10.6.1.3 ***Individual Factors***

Failures that are identified due to individual endeavour must be clearly specified e.g., mental judgemental failure (error). Where failures are due to cognitive error, it should be investigated to find out whether the root cause is stress, fatigue, lack of knowledge, communication or influence of sea etc, and be recorded accordingly. If however, failure is due to negligence, it should be investigated with no threat for punishment since the act of negligence may be influenced by stress, boredom, clumsy procedures, disturbances due to sea conditions, welfare, multiple tasks, lack of crew risk appreciation etc. These factors are key to understanding the pattern of behaviour and what must be address in human reliability.

Failures perceived due to breach must be thoroughly searched and if possible identify how design can be improved to meet operational needs or crew for resiliency.

10.6.1.4 *Environmental Factors*

Environmental factors include all incidences that occur during operations due to the influence of weather and sea conditions.

10.6.1.5 *Representation and Incorporating Stressors*

In maritime operations, personnel become overwhelmed with fatigue and stress due to workload, work environment and aggravated by sea conditions. In Chapter 10, it was highlighted that both quantities (combined work stress and sea effect) are difficult to quantify and that these stressors limit human reliability at sea by 18%. This was just uncovered in this research work, and so far, no work has been published on how to measure combined effect of work stress and sea induced fatigue on crew. Strategic planning is crucial at the end of every voyage so that the next voyage must be made to tally with sea condition.

Therefore, further studies are recommended to investigate how work stress and sea induced fatigue can be synchronised with voyage planning and manning to determine the combine effect on personnel. Such study should investigate how planning, work at harbour, weather focus and manning can be quantified for input into HRA. Such study will surely unveil the crew residual stress at the start and end of every voyage.

10.6.1.6 ***Representation of HRA Results***

Further work is recommended on explication and representation of human factors in HRA. This is to avoid the lump sum confusion where the human reliability result is given a single figure number which does not specifically show where gaps exist. In Chapter 7, detailed explication of human entropy into three components was suggested; as follows:

1. Human bit
2. Management part
3. Stressors

So far, except the HENT model, none of HRA models have presented human factor in a more transparent outfit. This classification clearly removes controversy and it is possible to see what went wrong. This proposal needs further amplification so that the hypothetical construct variables can be used directly to evaluate each component.

CHAPTER 11. Conclusion

This research work focused on human reliability analyses in particular, in the domain of maritime operations. A human reliability analysis model called HENT was developed as a new human reliability analysis tool. The maritime industry is one that is characterised by high consequence accidents in which fatalities can run into thousands. Accident reports have indicated gross acts of corner-cutting and risk-taking that are detrimental to system safety mechanisms. These unsafe acts have made it imperative to develop the Human Entropy model (HENT) as safety assessment tool. Reliability is data fixated; unfortunately most of the data bases on human factors are not reliable or even sufficient enough to provide the requisite information to quantify reliability. This is due to the complex nature of human factors ranging from: differences in individual capabilities, non-repeatability of errors, rapid changes in technology and disagreement among contending parties of the incident etc. In retrospection, in this study, tripartite human failure modes were uncovered. The Tripartite Human Failure Modes (THFM) revealed operational disorderliness which led to high consequences of accidents in maritime industry. The THFM are as follows in percentage contribution to failure:

1. Cognitive error 22%
2. Bounded rationality (breach) 17%
3. Extraneous acts (negligence) 60%.

Thus, failures due to human factor are not restricted to human error, but are also inclusive of volitional acts. These volitional acts are motivated either by influence of management, sea condition or by crew impulse, efficiency-thoroughness tradeoffs etc.

The *raison d'être* for the volitional acts are quite enormous and are inevitable in maritime operations due to work place exigencies. Man machine interface is therefore complex and the only way out is to exploit the Human Entropy Boundary Conditions (HEBCs) and develop utilities that can improve human resiliency to disturbance. The notion of human error is fundamentally wrong because the scope of the problem is limited. This study uncovered gross human disorderliness in operation and the cognitive error which is widely promulgated contributes only 22% in human failure mode. Therefore, the *Human Entropy* (HENT) was used as a detour from human error. Nine human entropy boundary conditions were expounded as generic performance shaping factors. The probabilistic impact of each of the nine HEBCs on human performance was determined as follows in order of importance: Crew quality, Training, Supervision, Logistics, Procedure, Communication, Welfare, Stress and Environment.

The HENT model incorporated the nine HEBCs in the form of construct variables, offering flexibility and supporting iteration under various scenarios. The concept of modelling human error in HRA is not enough to reveal unreliability in operations and mitigate unsafe acts. Failure due to human element is not limited to cognitive error but inclusive of extraneous acts and bounded rationality. This type of human disorderliness in operations is known as Human Entropy (HENT). Failures are not solely due to cognitive errors; rather may also be due to th*e legitimate* application of rationality or trade-offs. The conditions that influence human disorderliness were established qualitatively and quantitative as hypothetical construct variables, structured in a logic worksheet. The logic worksheet provides continuum of competing risks within operational domain as the input for the HENT analysis. Therefore, unlike existing HRA models, HENT model will provide a new dimension focussing on all kinds of human deviations in operations. The HENT model can provide operational reliability and audit risk factors for personnel, management and environmental factors. The result can enhance conceptual thinking by knowing risk concentrated area. The HENT model software is a very powerful tool for personnel training particularly for crew resource management. This has been demonstrated in the case study and has revealed an interesting result. A case study was undertaken to demonstrate and exploit the capabilities of the HENT modelling concept on Crew Quality Audit (CQA). The results were quite astonishing and clearly demonstrated how crew appraisals can be exploited to improve crew quality for safe operations. These results serve as a tool which could be used for crew appraisals and to advise management on crew quality for appropriate deployment. Adjustments in the HENT model assessments can be performed through iteration of variables whilst documentation is supported at each instance. The graphical output provides an outright view of results in different colours and in order to facilitate mitigation, the areas needing urgent attention are highlighted in red. At the moment, the maximum human reliability at sea is limited to 0.81 and this is due to the influences of work stress and sea condition. The maximum attainable human reliability at sea is 81%. At the moment, these stressors are inevitable in operations unless, technology eliminates work stress and sea effect on personnel. Human performance at sea is inseparable from disturbance imposed by constraints such as rest periods which have a sinusoidal pattern (cyclic).

Overall, as this is entirely a new concept, further studies are highly recommended for future work. This is envisaged to further the development in HRA, and to achieve greater safety and facilitate mitigation of risks.

REFERENCES:

ABS (2000). Risk Assessment Applications for the Marine and Offshore Oil and Gas Industries. New York, Act of Legislation.

Allen N. (1982). "The knowledge level." Artificial Intelligence 18(1): 87-127.

Arslan O. (2009). "Quantitative evaluation of precautions on chemical tanker operations." Process Safety and Environmental Protection 87(2): 113-120.

Arslan, O. and I. D. Er (2008). "SWOT analysis for safer carriage of bulk liquid chemicals in tankers." Journal of Hazardous Materials 154(3): 901-913.

Aspinall (2008). "Expert Judgement Elicitation using the classical model and EXCALIBUR." seventh session of the statistics and risk assessment section's.

Bai, Y. (2003). Human Reliability Assessment. Marine Structural Design. Oxford, Elsevier Science: 579-588.

Bainbridge, L. (1983). "Ironies of automation." Automatica 19(6): 775-779.

Baker and Seah (2004). "Maritime Accident and Human Performance: The Statistical Trail.

Barnard P (1987). Cognitive resources and the learning of human -computer dialogs. in interfacing thought -Aspects of human computer interraction Cambride MA: MIT press.

Barrett, M. (2005). "Search for the Root Causes of Marine Casualities - Individual competence or Organisational culture." WMU Journal for Maritime Affairs 4(2): 131-145.

Bedford and Cooke (2006). "*Probabilistic Risk Analysis-Foundations and Methods*."

Bieder C, LeBot, et al. (1998). “MERMOS: EDF’s New Advanced HRA Method, International Conference on Probabilistic Safety Assessment and Management London, Springer Verlag

Blom, Henk, Mariken and Everdij. (2008) "Safety Methods Data Base."

Ronald, Boring, et al (2008). "Issues in benchmarking human reliability analysis methods: A literature review." Reliability Engineering & System Safety 95(6): 591-605.

BP (2010). Deepwater Horizon Accident Investigation Report.

Bram Wisse, and John Q (2008). "Expert judgement combination using moment methods." Reliability Engineering and System Safety 93: 675-686.

Broadbent, D. E., Cooper, P.F., FitzGerald, P., & Parkes, K.R. (1982). "The Cognitive Failures Questionnaire (CFQ) and its correlates." British Journal of Clinical Psychology, 21, 1-16. 21:

Bryant (1991). *The Human Element in Shipping Casualties,* Report prepared for the Dept. of Transport, Marine Directorate, United Kingdom

Byrne and Gray (2003). "Returning Human Factors to an Engineering Discipline: Expanding the Science Base through a New Generation of Quantitative Methods." HFES Vol. 45(1): 1-4.

Cacciabue, P. C. (2000). "Human factors impact on risk analysis of complex systems." Journal of Hazardous Materials 71(1-3): 101-116.

Card and Moran (1983). *The psychology of human -computer interraction*, lawrence erlbaum associates.

Celik, M. and S. Cebi (2009). "Analytical HFACS for investigating human errors in shipping accidents." Accident Analysis & Prevention 41(1): 66-75.

Club U (1992). Analysis of major claims, The United Kingdom Mutual Steam Ship Assurance Association (Bermuda) Limited.

Cooke and Elizabeth (2003). "Peirce, fallibilism, and the science of mathematics." Philosophia Mathematica 11(2).

Cooke (1991). Experts in Uncertainty, Oxford University Press.

Crawley, Preston, et al. (1990). "A managers Guide to Reducing Human Error." IChemE HAZOP Guide to best Practice.

David G. (2005). "Using simulation to determine framework for the objective of assessment of competence in maritime crises management." SAGSET 2005 Conference.

David G., (1994). Human Reliability and Safety Analysis Data Handbook, John wiley & sons.

David V. (1997). Quantitative Risk Analysis- A guide to Monte Carlo Simulation Modelling, Wiley.

Dougherty, E. (1987). Comparison of Time Reliability Correlations. New York.

Duffey, R. B. and J. W. Saull (2008). Managing risk: the human element, Wiley Publishing.

Eleye-Dotubo and Wall, (2008). "Marine and offshore safety assessment by incorporating Risk modelling in Fuzzy-Beyesian network of an induced mass assignment paradigm." Risk Analysis 28(1): 95-112.

Eleye-Dotubo W, A.G Wall, (feb 2008). "Marine and offshore safety assessment by incorporating Risk modelling in Fuzzy-Beyesian network of an induced mass assignment paradigm." Risk Analysis 28(1): 95-112.

El-Ladan and Turan, (2010). Human Reliability Analysis. Paradigm shift: From Human Error to Human Entropy. International Conference on Human Performance at Sea. Glasgow. UK

Embrey, Humphreys, et al. (1984). SLIM-MAUD: An Approach to Assessing Human Error Probabilities Using Structural Expert Judgement. B. N. l. Department of Nuclear Energy and US Nuclear Regulatory Commission, NUREG/CR-3518, (BNL-NUREG-51/16),.

Eyring, V, Isaksen, et al. (2010). "Transport impacts on atmosphere and climate: Shipping." Atmospheric Environment 44: 4735-4771.

French, S., T. Bedford, et al. "Human reliability analysis: A critique and review for managers." Safety Science 49(6): 753-763.

Fujita, Y. and E. Hollnagel (2004). "Failures without errors: quantification of context in HRA." Reliability Engineering & System Safety 83(2): 145-151.

Gertman, D. and Blackman (1994). *Human Reliability and Safety Analysis Data Handbook*, Wiley &sons.

Gertman, D., H. Blackman, et al. (2004). *The SPAR-H Human Reliability Analysis Method*. , US Nuclear Regulatory Commission.

Gordon R, Flin, et al. (2005). "Designing and evaluating a human factors investigation tool (HFIT) for accident analysis." safety science 43(3): 147-171.

Guarin, L., D. Konovessis, et al. (2009). "Safety level of damaged RoPax ships: Risk modelling and cost-effectiveness analysis." Ocean Engineering 36(12â€“13): 941-951.

Gulland, A (2006). "Can Technology Eliminate Human Eroor?" Process Safety and Environmental Protection, 84(B3): : 171-173.

Gunter, W. (1990). Why Accidents Happen: The Theories of Causation. http://www.todaydocs.com/list.php?keyword=CAUSATION&type=doc, *faculty.ycp.edu/~chertig/Accident%20Causation%20Theory.doc*.

Harrald, J, A. Mazzuchi, et al. (1998). "Using system simulation to model the impact of human error in a maritime system." Safety Science 30(1–2): 235-247.

Harris, D., Yang, et al. (2007). A Review of Current Human Reliability Assessment Methods Utilized in High Hazard Human-System Interface Design. Engineering Psychology and Cognitive Ergonomics, Springer Berlin Heidelberg. 4562: 212-221.

Haug, E. G. (2004). Why so Negative to Negative Probabilities ? ICBI Global Derivatives Conference. W. magazine. Madrid, Spain.

Helmreich, R. L., Merritt, A.C., & Wilhelm, J.A. (1999) (1995). "University of Texas at Austin Human Factors Research Project: 235 The evolution of Crew Resource

Management training in commercial aviation." International Journal of Aviation Psychology, 9(1): 19-32.

Hetherington C, Flin, et al. (2006). "Safety in shipping: the human element." Journal of safety research 37: 401-411.

Hollnagel, E. (1996). "Reliability analysis and operator modelling." Reliability Engineering & System Safety 52(3): 327-337.

Hollnagel, E. (1998). Chapter 6 - CREAM A Second Generation HRA Method. Cognitive Reliability and Error Analysis Method (CREAM). Oxford, Elsevier Science Ltd: 151-190.

Hollnagel, E. (1998). .Cognitive Reliability and Error Analysis Method. , Elsevier.

Hollnagel E (2000). "Looking for errors of omission and commission or The Hunting of the Snark revisited." Reliability Engineering and System Safety 68(2): 135-125.

Hollnagel E, (2006). *Resilience Engineering. Concepts* and Precepts, Ashgate Pub Co.

Hollnagel E, (2009). The ETTO Principle: Efficiency-Thoroughness Trade-Off ; Why Things That Go Right Sometimes Go Wrong, Ashgate.

HRM (2002). Evaluating stress measurement questionnaires. British Psychological Society Occupational Psychology Conference H. R. M. Guide, http://www.hrmguide.co.uk/worklife/stress_measure.htm.

Health and Safety Executives (2001). Safety Culture Maturity Model (SCMM), HSE offshore technology.

Health and Safety Executives (2007). Reducing error and Influencing behaviour.

Hudson, Reason, et al. (1994). "Tripod Delta: Proactive Approach to Enhance Safety." Society of Petroleum Engineers 46(1).

IAEA (1990). Human error classification and data collection. TECDOC-538. Vienna.

IMO (2002). Guidelines for FSA for use in the IMO rule - making progress, IMO. A.500(XII).

Isaac, A., S. T. Shorrock, et al. (2002). "Human error in European air traffic management: the HERA project." Reliability Engineering & System Safety 75(2): 257-272.

Kaplan, Stanley, et al. (1981). "Kaplan, Stanley and B. John Garrick (1981) “On The Quantitative Definition of Risk”." Risk Analysis 1: 11-27.

Kelvin, (2009). Human Factors & Incident Investigation.

Kim, J. W. (2003). "A taxonomy of performance influencing factors for human reliability analysis of emergency tasks." Loss Prevention in the process industry - Elsevier 16(6): 479-495.

Kirwan (1997). "The development of a nuclear chemical plant human reliability management approach:

HRMS and JHEDI*." Elsevier Science Limited 56(2): 107-133.

Kirwan, B. (1992). "Human error identification in human reliability assessment. Part 1: Overview of approaches." Applied Ergonomics 23(5): 299-318.

Kirwan, B. (1992). "Human error identification in human reliability assessment. Part 1: Overview of approaches." science direct 23(5): 299-318.

Kirwan, B. (1994). *A Guide to Practical Human Reliability Assessment*, Taylor and Francis.

Kletz, T. (1999). "HAZOP and HAZAN; Identifying and assessing process industry hazards."

Knudsen, O. F. and B. r. Hassler "IMO legislation and its implementation: Accident risk, vessel deficiencies and national administrative practices." Marine Policy 35(2): 201-207.

Konstandinidou, Myrto, et al. (2006). "A fuzzy modeling application of CREAM methodology for human reliability analysis." Reliability Engineering & System Safety 91(6): 706-716.

Leveson, N. (2004). "A New Accident Model for Engineering Safer Systems." Safety Science 42(4): 237

Leveson N (2004). "A new accident model for engineering safer systems." Safety Science 42(4): 237-270.

Likert R (1932). "A technique for the measurement of attitudes. ." RArchives Psychology 140: 44-55.

Linda T. Kohn, J. M. C., and and M. S. Donaldson (2000). "To err is human: Building a Safer Health." National Academy Press Washington, D.C.

Lloyds List (2010). Information Resources on the AL SALAM BOCCACCIO 98, International Maritime Organisation (IMO).

Marlow, T. (1992) "On the Probabilistic Compatibility of Special Relativity and Quantum Mechanics."

Menezes LM, B. D., Taylor Jw (2000). "review of guidelines for the used of combine forecasts." European journal of operational research 120: 190-204.

Michael Berry (2003). *Quantum chaology Physics Department, University of Bristol Physicspp104-5 of Quantum: a guide for the perplexed by Jim Al-Khalili (Weidenfeld and Nicolson*

Mohaghegh, Z., R. Kazemi, et al. (2009). "Incorporating organizational factors into Probabilistic Risk Assessment (PRA) of complex socio-technical systems: A hybrid technique formalization." Reliability Engineering & System Safety 94(5): 1000-1018.

Mohaghegh, Z., R. Kazemi, et al. (2009). "Incorporating organizational factors into Probabilistic Risk Assessment (PRA) of complex socio-technical systems: A hybrid technique formalization." Reliability Engineering & System Safety 94(5): 1000-1018.

Montmayeul, R., F. d. r. Mosneron-Dupin, et al. (1994). "The managerial dilemma between the prescribed taks and the real activity of operators: Some trends for research on human factors." Reliability Engineering & System Safety 45(1â€“2): 67-73.

Mosleh, A. and Y. H. Chang (2004). "Model-based human reliability analysis: prospects and requirements." Reliability Engineering & System Safety 83(2): 241-253.

Murphy, A. H. and R. L. Winkler (1979). "Probabilistic Temperature Forecasts: The Case for an Operational Program." Bulletin of the American Meteorological Society 60(1): 12-19.

Muruki E (1990). "Fitting a polynomial item response model to likert type data." Applied psychology measurement 14(1): 59-71.

NEA (1998). Critical operator actions: human reliability modelling and data issues. EA/CSNI/R(98)1, http://www.oecd-nea.org/nsd/docs/1998/csni-r98-1.pdf.

NRC (1975). Reactor safety study. Washington, Nuclear regulatory Commission.

Le Bot, Desmares, et al. (1998). "MERMOS: un projet d'EDF pour la mise à jour de la méthodologie EPFH." Revue Générale Nucléaire

Parker, A., Hubinger, et al. (2002). Health stress and fatigue in shipping: Australian Maritime Safety Agency.

Parola, F. and Veenstra (2008). "The spatial coverage of shipping lines and container terminal operators." Journal of Transport Geography 16: 292-299.

Paulk, M. (1993). "Capability Maturity Model." IEEE 10 (4): 18-27.

Psarros G, Skjong, et al. (2010). "Under Reporting of Marine Accidents." Accident Analysis and Prevention, Elsevier 42: 619-625.

Psarros, G., Skjong, et al. (2010). "Under Reporting of Marine Accidents." Accident Analysis and Prevention, Elsevier 42: 619-625.

Pykacz1, J. (2006). "“Solution” of the EPR Paradox: Negative, or Rather Fuzzy Probabilities Foundations of Physics, 36(3).

Raby M and Mccallum (1997). "Procedures for investigating and reporting fatigue contributions to marine casualties. ." Human Factors and Ergonomics Society 41st Annual Meeting.

Rasmussen, J. (1982). "Human errors. A taxonomy for describing human malfunction in industrial installations." Journal of Occupational Accidents 4(2-4): 311-333.

Rasmussen, J. (1998). "Risk Management in Dynamic Society: A Modelling Problem." Safety Science 27(2/3): 183-213.

Rassmusen (1975). Reactor Safety Study: An assessment of accident risks . US Nuclear Regulatory Commission, NRC, WAsH-1400.

Reason J (1990). *Human Error,* Cambridge University.

Reason J (1997). *Managing the Risks of Organisational Accidents*.

Rothblum, A. R. (2000). Human error and marine safety. Paper presented at the National Safety Council Congress and Expo Orlando, FL.

Salmon, P. M., M. G. Lenné, et al. (2010). "Managing error on the open road: The contribution of human error models and methods." Safety Science 48(10): 1225-1235.

Savage LJ (1971). "Elicitations of personal probabilites and expectations." Journal of the American statistical association 66(336).

Schroder-Hinrichs Shifrin and Tash (2007). Human Error Causes Most Data Loss, Study IDg News.

StrÃter, O. and H. Bubb (1999). "Assessment of human reliability based on evaluation of plant experience: requirements and implementation." Reliability Engineering & System Safety 63(2): 199-219.

Swain, A. (1987). Accident Sequence Evaluation Program Human

Reliability Analysis Procedure. Reliablity Engineering and Safety Science. Washington, DC NUREG/CR-4772 (US Nuclear Regulatory Commission).

Swain, A. (1990). "Human Reliability Analysis: Needs, Status, Trends and Limitations." Reliability Engineering & System Safety 29: 301-313.

Taylor-Adamas (1997). "CORE-DATA: A Computerised Human Error Database for Human Reliability

Support." IEEE XPLORE Sith Annual Human Factors Meeting 1997 IEEE: 9/7-912.

Taylor, P. (2001). Risk Homeostasis. http://www.nous.org.uk/risk.html.

Timmer, J. (2010). "BP's oil spill report traces a cascade of epic fail " ars technica.

Torell and Avelar (2004). Mean Time Between Failure: Explanation and Standards White Paper #78 American Power Conversion.

Turan, O. and S. B. El-Ladan (2012). "Human Reliability Analysis- Taxonomy and praxes of human entropy boundary conditions for marine and offshore applications." Reliability Engineering and System Safety 98(1): 43-54.

Tversky and Kahneman (1992). "Advances in Prospect Theory: - Cumulative Representation of Uncertainty." Journal of Risk and Uncertainty: 5:297-323 (

Uchida, M. (2004). Analysis of human error in Marine Engine Management. . Advances in International Maritime Research. Proceedings of Annual General Assembly No 5., Tasmania,IAMU.

Van Urk, W. and W. A. de Vries (2000). "POLSSS: policy making for sea shipping safety." Safety Science 35(3): 139-150.

Vanderhaegen, F. (2001). "A non-probabilistic prospective and retrospective human reliability analysis method application to railway system." Reliability Engineering & System Safety 71(1):

Vanem, E. and J. Ellis "Evaluating the cost-effectiveness of a monitoring system for improved evacuation from passenger ships." Safety Science 48(6): 788-802.

Victor, R. and R. Parasuraman (1997). "Humans and automation: use, misuse, disuse, abuse." Human Factors and Argonomics society 39(2): 230-253.

Wagenaar and G. J. (1987). Accidents at sea: Multiple causes and impossible consequences. *Int. J. Man-Machine Studies, 27,* : 587-598.

Wang, J. (2007). *Design for safety of Marine and Offshore Systems*.

Wang J (2007). *Design for safety of Marine and Offshore Systems*.

Werndl C (2009). "What are the new implications of chaos for unpredictability?" British Journal for Philosophy of science 60(1): 195-220.

Wiegmann, D. (2001). "A Human Error Analysis of Commercial Aviation Accidents Using the Human Factors Analysis and Classsification system (HFACS)." US Department of Transport.

Wiggins, J. S. (1996). The Five-Factor Model of Personality - Theoretical perspectives, The Guilford Press.

Wilde (2001). Target risk 2: a new psychology of safety and health: what works,What doesn’t , And why. Toronto, PDE Publications.

Wiley Jee and Benjamin (2007). "How goals affect the organization and use of domain knowledge " *Memory & Cognition, Psychonomic Society, Inc.* 35(5): 837-851.

Williams, J. C. (1985). "Validation of human reliability assessment techniques." Reliability Engineering 11(3): 149-162.

Woods, D. (2007). Perspectives on Human Error: Hindsight Biases and Local Rationality. Cognitive Systems Engineering Laboratory Institute for Ergonomics. The Ohio State University.

Yang, Z. and W. J. (2011). "quantitative Retrospective Analysis of CREAM in Maritime Operations." Advances in Safety, Reliability and Risk Management: 687-695.

Youngberg, Y. (2003). The patient safety Hand Book, Jones and Bartlett.

Appendixes

Appendix 1-1- Accidents by Qualitative Groupings for ATSB Data (Courtesy ABS)

Accident Group	Causal Factor	Count
Situation Awareness Group	Situation assessment and awareness	15
	Knowledge, skill and abilities	13
	Commission	2
	Total	30
Management Group	Fatigue	3
	Communications	4
	Bridge resource management	5
	Procedures	5
	Manning	2
	Business management	3
	Watch handoff	5
	Total	27
Risk Group	Risk tolerance	5
	Navigation vigilance	3
	Complacency	3
	Substance abuse	1
	Task omission	16
	Lookout failures	5
	Total	33
Maintenance Human Errors	Maintenance human error	3
	Total	3
Non Human Error Group	Uncharted hazards to navigation	1
	Material failure	6
	Weather	4
	Unknown course	5
	Total	16
Total Causes Identified:		109
Mechanical failure , etc:		16
Percent Human Error Related		*85%*

Appendix 2-11 ; Accident Statistics (UK) Courtesy IMO

Machinery				
SN	Vessel name	Vessel type	Accident type	Accident date
1	MOON CLIPPER	High-speed catamaran	Steering control failure and subsequent contact on the River Thames, resulting in injuries to several passengers and crew.	5/10/2011
2	PRIDE OF CALAIS	Ro-Ro vessel	Machinery failure leading to contact with the berth in Calais, France.	22/10/2011
3	SAFFIER	Cargo vessel	Failure of the controllable pitch propeller resulting in heavy contact with a berthed tug in Immingham harbour.	25/06/2011
4	BLUE NOTE (NO 7/2012)	Dry cargo vessel	Derailment of the hatch-lid gantry crane while alongside in Londonderry, Northern Ireland	22/07/11
5	CLONLEE	Feeder container vessel	Electrical blackout and subsequent grounding on the River Tyne	16/03/11
6	RMS QUEEN MARY 2	Cruise vessel	Catastrophic capacitor failure in the aft harmonic filter room while approaching Barcelona	23/09/10
7	SAND FALCON (NO 16/2010)	Dredger	Failure of the stores crane	29/01/10
8	CORMORANT	Floating sheerleg	Lifting equipment failure	07/03/10
9	STELLAR VOYAGER	Oil tanker	Catastrophic failure of a windlass hydraulic motor resulting in a major injury, off Tees Bay	23/03/09
10	MOONDANCE	Ro-ro cargo vessel	The electrical blackout and subsequent grounding of Moondance in Warrenpoint Harbour, Northern Ireland	29/06/08

11	FIGARO	Vehicle carrier	Inadvertent release of Carbon Dioxide and disabling of vessel	06/12/07
12	MSC NAPOLI	Container vessel	Structural failure of UK flagged container vessel	18/01/07
13	MAESK DOHA	Container vessel	Machinery breakdown and subsequent fire onboard	02/10/06
14	P&O NEDLLOYD GENOA	Cargo vessel	Loss of cargo containers overboard	27/01/06
15	SAVANNA EXPRESS	Container vessel	Engine failure and subsequent contact with linkspan at Southampton Docks.	19/07/2005
16	PRIDE OF PROVENCE	Dry bulk carrier	Failure of the starboard bow door on Pride of Provence at Calais	22/02/04
17	NORSEA	Ro-ro ferry	Failure of a low-pressure fuel pipe on the main diesel generator resulting a in fire in the aft engine room of Ro-ro ferry Norsea	02/09/02
18	MARINE EXPLORER	Lifeboat	Failure of lifeboat winch brake on Marine Explorer in Harwich,with two injured	14/03/01
19	RANDGRID	Shuttle Tanker	Parting of mooring line between the Tetney buoy and the North Sea shuttle tanker Randgrid resulting in the discharge of 12 tonnes of crude oil into the Humber Estuary	20/12/00
20	EUROPEAN HIGHWAY	Lifeboat/Fast Rescue Craft	Accident to lifeboat and fast rescue craft from European Highway in Zeebrugge, four injured	01/12/00
21	PRIDE OF BILBAO	Rescue boat	Rescue boat falling from Pride of Bilbao into Cherbourg Harbour injuring two people	01/07/00

22	AQUITAINE	Lifeboat	Failure of lifeboat gear on vessel in Falmouth dry-dock	29/10/99
23	P&OSL CALAIS	Ro-ro passenger ferry	Failure of No 5 lifeboat winch on 25 June 1999, and related investigation into self-lifting sprag clutch behaviour	27/06/99
24	DEA FIGHTER	Fast rescue craft	Investigation of two lifting wire failures on starboard Fast Rescue Craft davit of safety stand-by vessel	13/05/99 and 16/07/99
25	ISLAND PRINCESS	Cruise Liner	Rupture of the port economiser on board resulting in two deaths	07/12/97
26	SYMPHONY	Class V Passenger Vessel	Steering failure and subsequent collision with Lambeth Bridge on River Thames	04/10/99
27	ARCADIA	Cruise ship	Lifeboat winch failure on passenger cruise ship	09/12/99
28	ENAK/LOVELETTER	General cargo	Failure of lifting arrangement in Sunderland Docks with loss of one life	09/05/97
29	PRIDE OF HAMPSHIRE	Ro-ro vehicle passenger ferry	Lifeboat accident on a Ro-ro passenger vessel	25/09/94
30	HAYKONG	Liquid Petrolium Gas Tanker	A joint MAIB/HSE investigation into an incident at Braefoot Bay Terminal by Aberdour, Fife	23/01/93
31	HOEGH DUKE	Bulk carrier	Lifeboat accident with six seamen killed and six others hospitalised	20/08/92
32	MOBIL PETREL	Oil tanker	Over pressurisation of cargo tank	28/11/91
FIRE AND EXPLOSION				
1	VESSEL NAME	Vessel type	Accident type	Accident date
2	COMMODORE	Ro-ro passenger	Fire on the main vehicle deck	16/06/10

	CLIPPER	ferry		
3	YEOMAN BONTRUP	Bulk Carrier	Fire and explosion	2/07/10
4	OSCAR WILDE (NO 3/2011)	Roro passenger ferry	Machinery space fire.	2/02/10
5	MEERSK NEWPORT (NO 13/2009)	Container ship	Investigations of heavy weather damage 50 miles west of Guernsey and a fire alongside in Algeciras, Spain.	10/11/08 & 15/11/08
	LADY CANDIDA (NO 4/2008)	Large charter yacht	Fire and subsequent sinking	28/07/07
6	MAERSK DOHA (NO 15/2007)	Container vessel	Machinery breakdown and subsequent fire onboard	02/10/06
7	CALYPSO (NO 8/2007)	Passenger cruise vessel	Engine room fire on board the passenger cruise vessel The Calypso 16 miles south of Beachy Head	06/05/06
8	HILLI (NO 4/2007)	Liquid natural gas tanker	Starboard boiler explosion resulting in one fatal and one serious injury on board, Grand Bahama Shipyard Freeport, Grand Bahama	10/10/03
9	STAR PRINCESS(NO 28/2006)	Cruise ship	Fire onboard Star Princess off Jamaica	23/03/06
10	NOSEA(NO 16/2003)	Ro-ro ferry	Fire in the aft engine room of Ro-ro ferry Norsea	02/09/02
11	PRIDE BATH(NO 6/2003)	Pleasure cruiser	A barbecue fire in the galley of Pride of Bath on the River Avon, Bath	20/07/02
12	STENA EXPLORER(NO 5/2003)	Highspeed catermaran	Fire on board HSS Stena Explorer entering Holyhead	20/09/01
13	ROSEBANK(NO 28/2002)	General cargo vessel	Accommodation fire on mv Rosebank 7 miles east of	14/12/01

			Alnmouth, off the Northumberland coast	
14	STHELINA(NO 19/2001)	Class 1 passenger ship	Engine room fire	25/08/00
15	TOISA GRYPHON (NO 1/2000)	Offshore tug/supply vessel	Engine room fire 150 miles west-south-west of Isles of Scilly	02/02/99
16	EDINGBURGH CASTLE	Class 1 Passenger Ship	Fire in main galley of vessel	21/08/98
17	PRIDE OF LE HAVRE	Ro-ro cargo vessel	Switchboard explosion	27/07/98
18	PRIDE OF LE HAVRE	Ro-ro cargo vessel	Engine room fire	18/03/99
19	SAGA ROSE	Passenger cruise liner	Fire on the passenger cruise liner whilst undergoing a refit at the A&P Docks, Southampton	14/12/97
20	ESSO MERSEY (MT)	Motor tanker	Re-opened inquiry into the explosion on a motor tanker, with the loss of two lives	04/09/91
21	ESSO MERSEY (MT)	Motor tanker	Explosion on board a motor tanker, with the loss of two lives	04/09/91
22	SALLY STAR	Ro-ro passenger vessel	Fire on board	25/08/94
23	ONWARD(NO 27/2012)	Fishing vessel	Fire on board the fishing vessel 60nm off the coast of Scotland resulting in the loss of the vessel	11/04/12
24	VISIONII(NO 8/2009)	Fishing vessel	Fire on board fishing vessel while alongside in Fraserburgh	1/08/2008
25	ELEGANCE(NO 9/2004)	Fishing vessel	Two engine room fires, subsequent flooding and foundering of the fishing vessel Elegance 30 miles north-west of Shetland on 30 January 2004	30/01/04 and 05/03/04

			and 8.5 miles west of Shapinsay on 5 March 2004	
26	KING FISHER II(NO 15/2004	Fishing vessel	Fire on board the fishing vessel Kingfisher II whilst on passage to recover creels, 5 miles east of North Uist	26/04/04
27	FLEUR.DE.LYS (NO 36/2001)	Fishing vessel	Explosion on board vessel which then foundered 18 miles south-east of Portland Bill	16/04/00
28	ROSS ALCEDO (NO 3/2001)	Fishing vessel	Fire on board vessel while underway about 32 miles north-west of the Isles of Scilly	16/01/00
29	BE READY(NO 30/2000)	Fishing vessel	Fire on board vessel while fishing 30 miles north-west of the Orkney Islands	22/01/00
30	DE.KAPER	Trawler	Fire on board trawler off Hanstholm, Denmark	12/02/99
GROUNDING				
1	VESSEL NAME	Vessel Type	Accident Type	Accident Date
2	MOYUNA (NO 17/2012)	Fishing vessel	Grounding at the entrance to Ardglass Harbour, Northern Ireland	21/11/11
3	KAREN SCHEPARS (NO 10/2012)	Container vessel	Grounding at Pendeen, Cornwall, UK	03/08/11
4	CLONLEE (NO 6/2012)	Feeder container vessel	Electrical blackout and subsequent grounding on the River Tyne	16/03/11
5	GOLDEN PROMISE (NO 3/2012)	Fishing vessel	Grounding on the Island of Stroma	7/09/11
6	CSI THAMES (NO 2/2012)	Bulk Carrier	Grounding in the Sound of Mull	9/08/11
7	K-WAVE (NO 18/2011)	Feeder container vessel	Grounding near Malaga, Spain	15/02/11
8	JACK ABRY II	Fishing vessel	Grounding on the Isle of Rum	31/01/11

	(NO 14/2011)			
9	KAREN (NO 9/2011)	Fishing vessel	Grounding at the entrance to Ardglass Harbour, County Down in Northern Ireland	3/01/11
10	KERLOCH (NO 12/2010)	Fishing vessel	Grounding & subsequent foundering	20/02/10
11	MAERSK KENDAL (NO 2/2010)	Container vessel	Grounding on Monggok Sebarok reef in the Singapore Strait	16/09/09
12	TS ROYALIST (NO 26/2009)	Sail training vessel	Grounding near Chapman's Pool off the south coast of the UK	5/04/09
13	SOOTY (NO 22/2009)	RIB	High speed grounding resulting in one fatality.	18/05/09
14	RIVERDANCE (NO 18/2009)	Ro-ro cargo vessel	Grounding and subsequent loss of ro-ro cargo vessel on Shell Flats - Cleveleys Beach, Lancashire	31/01/08
15	ANTAR (NO 7/2009)	General cargo vessel	Grounding of a general cargo vessel near Larne, Northern Ireland	29/06/08
16	MOONDANCE (NO 5/2009)	Ro-ro cargo vessel	The electrical blackout and subsequent grounding of Moondance in Warrenpoint Harbour, Northern Ireland	29/06/08
17	ASTRAL (NO 4/2009)	Chemical & oil tanker	Grounding of tanker on Princessa Shoal, East of Isle of Wight	10/03/08
18	PRIDE OF CANTERBURY (NO 2/2009)	Passenger ferry	Grounding of passenger ferry on "The Downs" - off Deal, Kent	31/01/08
19	SEA MITHRIL (NO 16/2008)	Cargo vessel	Grounding of Cargo vessel on River Trent	18/02/08
20	CFL PERFORMER (NO 21/2008)	Dry cargo vessel	Grounding on Haisborough Sand, North Sea.	12/05/08

21	ARCTIC OCEAN AND MARITIME LADY (No 2/2007)	Container/Dry cargo/Chemical tanker	Collision between Arctic Ocean and Maritime Lady, the capsize of Maritime Lady and contact with wreck of Maritime Lady by Sunny Blossom, and its subsequent grounding in the Elbe River	05/12/05
22	OCTAPUS/HARALD (No 18/2007)	Jack-up barge / Tug	Grounding of the jack-up barge, towed by the Tug, in Stronsay Firth, Orkney Islands	08/09/06
23	AQUA-BOY (No 14/2007)	Steel live fish carrier	Grounding in the Sound of Mull	11/11/06
24	HARVEST CAROLINE (No 13/2007)	General cargo	Grounding north-west coast of Scotland	31/10/06
25	THUNDER (No 12/2007)	General cargo	Grounding at the approaches to the Dee Estuary	10/08/06
26	KATHRIN (No 24/2006)	Combi freighter	Grounding	12/02/06
27	CP VALOUR (No 22/2006)	Container vessel	Grounding	09/12/05
28	DIEPPE (No 18/2006)	Ro-ro passenger ferry	Grounding	05/12/05
29	BERIT (No 17/2006)	Hatchless container ship	Grounding	05/01/06
30	ANGLIAN SOVEREIGN (No 16/2006)	Emergency Towing Vessel (ETV)	Grounding	03/09/05
31	LERRIX (No 14/2006)	General cargo	Grounding	10/10/05
32	BRITISH ENTERPRISE (No 25/2005)	Tanker	Grounding	11/12/04
33	SARDINIA VERA (No 19/2005)	Ro-ro ferry	Grounding	11/01/05

34	STOLT TERN (No 18/2005)	Product tanker	Grounding	01/12/04
35	BALMORAL (No 14 2005)	Passenger vessel	Grounding	18/10/04
36	JACKIE MOON (No 5 2005)	Cargo vessel	Grounding	01/09/04
37	TTILIO LEVOLI (No 2/2005)	Chemical tanker	Grounding	03/06/04
38	WAVERLY (No1 2005)	Passenger vessel	Grounding	20/06/04
39	HC KATIA (No 8/2004)	Ferry	Grounding	03/12/03
40	TRIDENT VI (No 1/2004	Inter-island passenger vessel	Grounding	23/08/03
41	JAMBO (No 27/2003)	General cargo ship	Grounding	29/06/03
43	PRIDE OF THE DART (No 12/2003)	Class VI passenger vessel	Grounding	28/06/02
44	SARDINIA VERA (No 32/2002)	Passenger ro-ro ferry	Grounding	01/02/02
45	WILLY (No 31/2002)	Product tanker	Grounding, in Cawsand Bay, Plymouth Sound	01/01/02
46	LYSYFOSS (No 23/2002)	Pallets carrier	Grounding	07/05/01
47	P&O NEDLOYD (No 18/2002)	Container ship	Grounding	20/02/01
48	FINNREEL (No 17/2002)	Ro-ro vessel	Grounding	14/03/01
49	STENA CHALLENGER	Ro-ro ferry	Grounding of a passenger Ro-Ro ferry at Blériot-Plage, Calais	19/09/95
50	BROTHERS (No 1/2007)	Stern trawler	Grounding with the loss of 2 lives	01/06/06
51	GREENHILL (No 19/2006)	Fishing vessel	Grounding and subsequent foundering with loss of two	19/01/06

			lives	
52	OUR NICHOLAS (No 26/2002)	Crabber	Grounding and loss	24/07/01
53	PRIMEROSE (No 13/2002)	Fishing vessel	Grounding	15/06/01
54	RESPLENDANT (No 10/2002)	Fishing vessel	Grounding	13/06/01
55	LOMUR (No 7/2002)	Fishing vessel	Grounding	14/06/01
56	AROSA (No 41/2001)	Fishing vessel	Grounding and total loss with the loss of 12 crew members	03/10/00
	HORIZONTE C (No 23/2001)	Fishing vessel	Grounding	21/10/00
57	BETTY JAMES (No 34/2000)	Fishing vessel	Grounding and subsequent loss of vessel	10/07/00
58	RACHEL HARVEY (No 23/2000)	Potter	Grounding and loss of vessel	01/10/99

Collision/Contact

1	Vessel Name	Vessel Type	Accident Type	Accident Date
2	STENA FERONIA (No 26/2012)	RoPax and cargo vessel	Collision in Belfast Lough, UK	7/03/2012
3	SPRING BOK (No 24/2012)	Cargo vessel and LPG Tanker	Collision 6nm south of Dungeness, UK	24/03/2012
4	MOON CLIPPER (No 21/2012)	High-speed catamaran	Steering control failure and subsequent contact on the River Thames, resulting in injuries to several passengers and crew.	5/10/2011
5	PRIDE CALAIS (No 18/2012)	Ro-ro vessel	Machinery failure leading to contact with the berth in Calais, France.	22/10/2011
6	CLIPPER POINT (No 16/2012)	Ro-ro cargo ferry	Contact between the ro-ro cargo ferry at the Port of	24/05/2011

			Heysham’s South Quay, and two berthed ships.	
7	CHIEFTON (No 12/2012)	Tug	Collision, capsize and foundering with the loss of one crewmember, at Greenwich Reach, River Thames.	12/08/2011
8	SAFFIER (No 9/2012)	Cargo vessel	Failure of the controllable pitch propeller resulting in heavy contact with a berthed tug in Immingham harbour.	25/06/2011
9	MORFIL AND SUN CLIFFER (No 8/2012)	Rigid-hulled inflatable boat and passenger vessel	Collision by Blackfriar's Road Bridge, River Thames.	1/06/2011
10	COSCO HONG KONG (No 27/2011)	Container vessel and Fish transportation vessel	Collision in the East China Sea resulting in the loss of 11 lives.	6/03/2011
11	CMA-CGM PLATON (No 26/2011)	Container vessel	Contact with Bevans Wharf, River Thames.	15/05/2011
12	SAPPHIRE II AND SILVER (No 21/2011)	Fishing vessels	Collision resulting in the foundering of Sapphire II off Stornoway, Scotland.	12/01/2011
13	PHILIPP AND LYNN (No 20/2011)	Container feeder vessel and fishing vessel	Collision 6nm south of the Isle of Man.	09/04/2011
14	CARDIFF BAY YATCH (No 19/2011)	RIB	Collision between two Cardiff Bay Yacht Club RIBs resulting in injuries to three students.	27/10/2010
15	BOXFORD ADMIRAL (No 17/2011)	Container vessel and Fishing vessel.	Collision 29nm south of Start Point.	11/02/2011
16	SKANDIA	Platform Supply	Contact with OMS Resolution	29/05/2010

	FOULA (No 15/2011)	vessel.	in Aberdeen Harbour.	
17	SBS TYPHOON (No 13/2011)	Platform Supply vessel.	Contact in Aberdeen Harbour.	26/02/2011
18	ANTONIS (No 10/2011)	Bulk carrier.	Contact with Langton-Alexandra swing bridge in the Port of Liverpool.	11/12/2010
19	NORMAN ARROW (No 7/2011)	High Speed Craft.	Contacts with quays in Portsmouth International Port, UK and with a mooring dolphin in Le Havre, France.	31/03/2010 and 29/08/2010
20	HOME LAND AND SCOTTISH VIKING (No 4/2011)	Fishing vessel & ro-ro passenger vessel.	Collision resulting in one fatality	5/08/2010
21	ISLE ARRAN (No 13/2010)	Roro vehicle passenger ferry	Contact by Isle of Arran with the linkspan at Kennacraig.	6/02/2010
22	ALAM PINTER (No 11/2010)	Bulk Carrier & Fishing vessel	Collision between the Singapore registered bulk carrier and UK registered fishing vessel 15 miles north of the Cherbourg peninsula resulting in one fatality and the loss of the fishing vessel.	20/12/09
23	SAETTA/CONGER (No 3/2010)	Merchant Tankers	Collision between mt Saetta and mt Conger on completion of a ship to ship transfer 9.5 miles south east of Southwold, UK	10/08/09
24	VALLERMOSA (No 23/2009)	Product tanker	Contact made by the tanker Vallermosa, with the tankers Navion Fennia and BW Orinoco at the Fawley Marine Terminal	25/02/09
25	SCOT ISLE & WADIHALFA	General cargo vessel/Bulk Carrier	Collision between Scot Isles and Wadi Halfa in the Dover	29/10/09

	(No 10/2009)		Strait	
26	SICHEM MELBOURNE (No 18/2008)	Chemical/products carrier	Contact with mooring structures at Coryton Oil Refinery terminal	25/02/08
27	URSINE (No 10/2008)	Ro-ro cargo vessel	Contact between Ursine and Pride of Bruges in King Georges Dock, Hull	13/11/2007
28	AUDACITY/LEONIS (No 2/2008)	Product tanker/Cargo vessel	Collision at the entrance to the River Humber	14/04/07
29	LOGOS II (No 1/2008)	Passenger ship	Two accidents during berthing and unberthing of Logos II St Helier, Jersey	20 & 26 June 2007
30	GAS MONARCH (No 25/2007)	Gas carrier/Sailing yacht	Collision between Gas Carrier and Sailing Yacht, 6 miles ESE of Lowestoft during the evening	16/04/07
31	PROSPERO (No 24/2007)	Product tanker	Loss of control of Product tanker and subsequent heavy contact with jetty at semlogistics terminal, Milford	10/12/07
32	SEA EXPRESS /ALASKA RAINBOW (No 22/2007)	Highspeed ferry/General cargo	Collision between Sea Express 1 and Alaska Rainbow on the River Mersey	03/02/07
33	SKAGERM (No 6/2007)	Container vessel/Cargo vessel	Investigation of the collision in the Humber Estuary	07/06/06
34	ARCTIC OCEAN (No 2/2007)	Container/Dry cargo/Chemical tanker	Collision between Arctic Ocean and Maritime Lady, the capsize of Maritime Lady and contact with wreck of Maritime Lady by Sunny Blossom, and its subsequent grounding in the Elbe River	05/12/05
35	REDM FELCON	Ro-ro passenger	Contact with the linkspan at	10/03/06

	(No 26/2006)	vehcle	Town Quay, Southampton	
36	HARVESTER (No 15/2006)	Supply and standby vessel/ Fishing vessel	Collision between fishing vessel Harvester and mv Strilmoy in the North Sea	04/11/05
37	LYKES (No 4/2006)	Container ship	Collision between Lykes Voyager and Washington Senator, Taiwan Strait	08/04/05
38	TJORNGARHT (No 21/2005)	Tug/Chemical tanker	Collision between Thorngarth and Stolt Aspiration, River Mersey, Liverpool	13/04/05
39	ORADE (No 23/2005)	General cargo vessel	Collision of a general cargo vessel with the Apex Beacon, River Ouse	01/03/05
40	Amenity/Tor Dania (No 20/2005)	Tanker/Ro-ro container	Collision between Amenity and Tor Dania south of Grimsby Middle, the River Humber, UK	23/01/05
41	Hyundai Dominion (No 17/2005)	Container vessels	Collision between Hyundai Dominion and Sky Hope in the East China Sea	21/06/04
42	Brenda (No 16/2005)	Aggregates dredger	Collision between Brenda Prior and Beatrice, Lambeth Pier, River Thames	17/12/04
43	Isle of Mull (No 13/2005)	Ro-ro vehicle/passenger ferry	Contact between Isle of Mull and Lord of the Isles and subsequent contact with Oban Railway Pier, Oban Bay	29/12/04
44	Scot Explorer (No 10/2005)	General cargo/Fishing vessel	Collision between Scot Explorer and Dorthe Dalsoe, Route ‘T’ in the Kattegat Scandinavia	02/11/04
45	Daggri (No 6/2005)	Ro-ro ferry	Contact made by the UK registered ro-ro ferry Daggri with the breakwater at Ulsta, Shetland Islands	30/07/04

46	Star Clipper (No 3/2005)	Class V passenger vessel	Failure of a mooring bollard resulting in a fatal accident at St Katherine's Pier, River Thames, London	02/05/05
47	Lord Nelson (No 14/2004)	Sail training vessel	Contact with Tower Bridge, London, River Thames	15/05/04
48	Reno (No 13/2004)	Chemical tanker/Fishing vessel	Collision	06/03/04
49	Scot Ventrue (No 11/2004)	General cargo vessel	Contact with Number 16 buoy by Scot Venture, Drogden Channel, Denmark	29/01/04
50	P&O Nedloyd (No 28/2003)	Container ship/Yacht	Collision	28/05/03
51	Nottingham Princess (No 21/2003)	River cruiser	Striking of Trent Bridge, Nottingham	15/11/02
52	(No 20/2003)	Passenger ro-ro ferry/Type 23 duke class frigate	Collision	27/10/02
53	(No 10/2003)	Passenger/Ro-ro cargo ferries	Collision	06/01/02
54	(No 8/2003)	General cargo	Striking the Keadby railway bridge	29/05/02
55	(No 7/2003)	General cargo/Chemical tanker	Collision	09/10/01
56	(No 41/2002)	Bulk carrier	Accident involving the starboard lifeboat of the bulk carrier	17/10/01
57	(No 39/2002)	Ro-ro ferry	Collision	02/04/02
58	(No 35/2002)	Dry cargo vessel	Collision and subsequent foundering	02/08/00
59	(No 30/2002)	General cargo ships	Collision	25/02/02
60	(No 20/2002)	Chain ferry	Collision between ferry and	25/06/02

			four yachts	
61	(No 19/2002)	Ro-ro passenger	Broaching of fast rescue boat while being launched from Commodore Clipper	18/02/01
62	(No14/2002)	Aggregates dredger/Fishing vessel	Collision	30/07/01
63	(No 12/2002)	General cargo/Refrigerated cargo	Collision	07/06/01
64	(No 9/2002)	Trawler/Ro-ro cargo	Collision	20/06/01
65	(No 5/2002)	Tanker/Fishing vessel	Collision	23/04/01
66	(No 40/2001)	General cargo/Feeder container	Collision	27/12/00
67	(No 30/2001)	Bulk carrier/Shuttle tanker	Collision between vessels, Immingham Oil Terminal	12/12/00
68	(No 31/2001)	Tank barge	Collision	21/12/00
69	(No 27/2001)	Ro-ro ferry	Impact with quay by ferry	27/04/00
70	(No 26/2001)	Cargo ship/Pleasure yacht	Collision between Wightstone and moored yacht.	09/11/00
71	(No 25/2001)	Ro-ro passenger ferry/Beam trawler	Collision	16/10/00
72	(No 18/2001)	Cargo/Bulk carrier	Collision	25/09/00
73	(No 15/2001)	Offshore supply vessel	Collision	27/01/00
74	(No 7/2001)	Cargo vessel/Container vessel	Collision between vessels off Texel Traffic Separation Scheme	13/06/00
75	(No 2/2001)	Feeder container ship/Fishing vessel	Collision	19/03/00
76	(No 35/2000)	Reefer/Bulk carrier	Collision	12/01/00
77	(No 32/2000)	Refridgerated	Collision with the Nab Tower	07/11/99

		cargo vessel		
78	(No 21/2000)	Fishing vessel/Container ship	Collision which lead to the foundering of Silvery Sea	14/06/98
79	(No 19/2000)	Cargo ship/Fishing vessel	Collision	02/09/99
80	(No 18/2000)	Class V passenger vessel	Steering failure and subsequent collision with Lambeth Bridge	04/10/99
81	(No 13/2000)	Fishing vessel/Offshore safety stand-by vessel	Collision	13/06/99
82	(No 8/2000)	Cargo vessels	Collision	02/03/99
83	(No 4/2000)	Fishing vessel/Ro-ro vehicle carrier	Collision	09/03/99
83	Published 21/04/95	Tanker/Bulk carrier	Collision	03/06/93
85	Published 10/09/92	Fishing vessel/Cargo vessel	Collision	10/04/91
86	Published 02/04/92	Passenger cruise ship	Re-appraisal of evidence relating to SS Californian	14/04/1912
87	Published 15/08/91	Passenger launch/Aggregates dredger	Collision	20/08/89
88	Harvester/Strilmoy (No 15/2006)	Supply and standby vessel/ Fishing vessel	Collision between fv Harvester and mv Strilmoy in the North Sea	04/11/05
89	(No 10/2005)	General cargo/Fishing vessel	Collision between Scot Explorer and Dorthe Dalsoe, Route 'T' in the Kattegat Scandinavia	02/11/04
90	(No 13/2004)	Chemical tanker/Fishing vessel	Collision	06/03/04
91	(No 11/2003)	Fishing vessel	Collision between UK	08/05/02

			registered fishing vessel and offshore platform in the Rough Gas Field about 25 miles south-east of Flamborough Head	
92	(No14/2002)	Aggregates dredger/Fishing vessel	Collision	30/07/01
93	(No 9/2002)	Trawler/Ro-ro cargo	Collision	20/06/01
94	(No 5/2002)	Tanker/Fishing vessel	Collision	23/04/01
95	(No 25/2001)	Ro-ro passenger ferry/Beam trawler	Collision	16/10/00
96	(No 2/2001)	Feeder container ship/Fishing vessel	Collision	19/03/00
97	(No 19/2000)	Cargo ship/Fishing vessel	Collision	02/09/99
98	(No 13/2000)	Fishing vessel/Offshore safety stand-by vessel	Collision	13/06/99
99	(No 4/2000)	Fishing vessel/Ro-ro vehicle carrier	Collision	09/03/99
100	Published 10/09/92	Fishing vessel/Cargo vessel	Collision	10/04/91
101	Published 09/07/92	Trawler/Submarine	Collision	22/11/90
Flooding/Foundering				
1	Vessel Name	Vessel Type	Accident Type	Accident Date
2	(No 12/2012)	Tug	Collision, capsize and foundering with the loss of one crewmember, at Greenwich Reach, River Thames.	12/08/11

3	(No 1/2012)	Fishing vessel	Flooding and foundering in the Little Minch.	6/08/11
4	(No 21/2011)	Fishing vessels	Collision resulting in the foundering of Sapphire II off Stornoway, Scotland.	12/01/11
5	(No 15/2009)	Grab hopper dredger	Investigation into the flooding and foundering of dredger Abigail H in Port of Heysham.	02/11/08
6	(No 17/2008)	Tug	Loss of tug Flying Phantom while towing Red Jasmine on the River Clyde, resulting in 3 fatalities and 1 injury.	19/12/07
7	(No 14/2003)	High Speed craft	Wash wave accident	18/07/02
8	(No 9/2003)	Passenger cruise ship	Flooding of aft engine	23/06/02
9	(No 35/2002)	Dry cargo vessel	Collision and subsequent foundering	02/08/00
10	(No 16/2002)	Ro-ro passenger vessel	Flooding	17/05/01
11	(No 29/2000)	Cargo vessel	Flooding to engine room	01/09/99
12	(No 21/2000)	Fishing vessel/Container ship	Collision which lead to the foundering of Silvery Sea	14/06/98
13	Adherence	Tug	Loss of tug in the Bay of Biscay	25/10/96
14	(No 1/2000)	Single deck cargo vessel	Foundering with the loss of four lives	25/04/1998
15		Workboat/tug	Capsize and foundering	08/09/98
16	Published 30/04/92	General cargo vessel	Abandonment and subsequent sinking of a motor vessel	January 1990
17	Published 02/05/91	Suction dredger	Loss of vessel with four lives	05/12/88
18	(No 7/2006)	Fishing vessel	Foundering	08/09/05
19	(No 3/2006)	Fishing vessel	Loss of vessel	30/06/05
20	(No 36/2001)	Fishing vessel	Explosion on board vessel which then foundered 18 miles south-east of Portland Bill	16/04/00

21	(No 1/2006)	19.43m scallop dredger	Sinking with seven fatalities	11/01/00
22	(No 9/2004)	Fishing vessel	Two engine room fires, subsequent flooding and foundering of the fishing vessel Elegance 30 miles north-west of Shetland on 30 January 2004 and 8.5 miles west of Shapinsay on 5 March 2004	30/01/04 and 05/03/04
23	(No 40/2002)	Fishing vessel	Flooding and loss of fishing vessel 78 miles west of St Kilda	13/08/01
24	(No 38/2001)	Fishing vessel	Flooding and foundering	18/03/01
25	(No 5/2001)	Fishing vessel	Flooding and foundering	23/03/00
26	(No 28/2000)	Charter fishing vessel	Flooding	03/07/99
27	(No 27/2000)	Gill netter	Loss of vessel with the loss of one life	08/01/00
28	(No 25/2000)	Trawler	Flooding and foundering	03/08/99
29	(No 24/2000)	Pelagic trawler	Foundering with the loss of one life	15/10/98
30	(No 14/2000)	Pair/stern trawler	Foundering	06/08/99
31	(No 12/2000)	Fishing vessel	Foundering	10/09/99
32		Fishing vessel	Sinking of the fishing vessel with the loss of six lives	02/11/98
33		Fishing vessel	Sinking of fishing vessel	30/07/99
34	(No 1/1999)	Fishing vessel	Sinking of fishing vessel with loss of four lives	01/10/97
35	Published 19/11/98	Fishing vessel	Loss of vessel with four lives	10/03/97
36	Published 22/09/98	Fishing vessel	Loss of fishing vessel with the loss of all six crew	February 1991
37	Published 23/07/98	Fishing vessel	Loss of vessel with three lives	23/07/98
38	Published 23/11/95	Fishing vessel	Loss of vessel with the loss of one life	03/12/94
39	Published 10/09/92	Fishing vessel	Loss of vessel with the loss of five lives	Between 10th-11th

				August 1991
40	Published 29/05/92	Fishing vessel	Loss of vessel with the loss of two lives	04/09/91
41	Published 27/02/92	Fishing vessel	Foundering	12/12/90
42	Published 05/07/91	Fishing vessel	Foundering with the loss of two crew members	24/11/89
43		Narrow boat	Foundering of narrow boat with the loss of four lives at Steg Neck lock near Gargrave, North Yorkshire	19/08/98
Listing/Capsize				
1	Vessel name	Vessel type	Accident type	Accident date
2	(No 12/2012)	Tug	Collision, capsize and foundering with the loss of one crewmember, Greenwich Reach, River Thames	12/08/11
3	(No 5/2010)	Fishing vessel	Capsize of a fishing vessel with the loss of three lives	20/07/09
4	(No 4/2010)	Tug	Loss of the tug Ijsselstroom in the port of Peterhead	14/06/09
5	(No 17/2008)	Tug	Loss of tug Flying Phantom while towing Red Jasmine on the River Clyde, resulting in 3 fatalities and 1 injury.	19/12/07
6	(No 17/2007)	Sloop	Capsize of an un-named sloop resulting in the loss of at least 60 lives.	04/05/07
7	(No 2/2007)	Container/Dry cargo/Chemical tanker	Collision between Arctic Ocean and Maritime Lady, the capsize of Maritime Lady and contact with wreck of Maritime Lady by Sunny	05/12/05

			Blossom, and its subsequent grounding in the Elbe River	
8	Swan (No 11/2005)	Passenger launch	Capsize of the passenger launch Swan on the River Avon, Bath	14/10/04
9	(No 24/2001)	Rigid Inflatable Boat (RIB)	Capsize of vessel off St Justinians, Ramsey Sound	28/09/00
10		Workboat/tug	Capsize and foundering	08/09/98
11	(No 32/2006)	Fishing vessel	Capsize with the loss of one crew	17/06/06
12	(No 30/2006)	Fishing vessel	Capsize with the loss of three crew	12/12/05
13	(No 21/2006)	Fishing vessel/trawler	Capsize and foundering	28/08/05
14	(No 2/2006)	9.8m trawler	Capsize and loss	23/05/05
15	Emerald Dawn/ Jann Denise II/ Kathryn Jane (15/2005)	Fishing vessels	Capsize and foundering/ Foundering/Foundering	10/11/04 17/11/04 28/07/04
16	(No 7/2004)	Fishing vessel	Capsize and sinking of the Chelaris J and loss of all crew members, Banc de la Schole (near Alderney)	01/10/03
17	(No 25/2003)	Fishing vessel	Loss of fishing vessel in the Firth of Forth	06/01/03
18	(No 19/2003)	Fishing vessel	Loss of vessel with the loss of her two crew, Firth Lorn	31/12/02
19	(No 15/2003)	Fishing vessel	Capsize of fishing vessel Flamingo East of Harwich	07/07/03
20	(No 2/2003)	Fishing vessel	Capsize and foundering of fishing vessel about 45 miles north-west of the Isle of Lewis with the loss of one life	10/04/02
21	(No 38/2002)	Fishing vessel	Capsize of the fishing vessel Charisma (OB588) with the	30/01/02

			loss of one crew member, Carlingford Lough	
22	(No 29/2002)	Fishing vessel	Investigation of the loss of Vertrauen about 75 miles north-east of Peterhead	19/07/01
23	(No 22/2002)	Stern trawler	Capsize and foundering	10/09/01
24	Constant Faith (No 21/2002)	Pair trawler	Loss of vessel	30/06/01
25	(No 8/2002)	Trawler	Loss of vessel	24/04/01
26	(No 37/2001)	Fishing vessel Potter/netter	Loss of fishing vessel	20/04/01
27	(No 14/2001)	Fishing vessel	Capsize and foundering	06/02/00
28	(No12a/2000)	Fishing vessel	Capsize	15/08/99
29	(No 11/2000)	Potter/creeler	Capsize with the loss of two lives	31/08/99
30		Fishing vessel	Loss of vessel with two lives	12/11/98
31		Fishing vessel	Capsize	13/10/98
32		Twin beam trawler	Capsize	27/07/98
33		Fishing vessel	Capsize and sinking of a fishing vessel west of the Shetland Islands, with the loss of five lives	13/06/89
Weather Damage				
S/N	Vessel name	Vessel type	Accident type	Accident date
1	Pacific sun (No 14/2009)	Cruise ship	Investigation of heavy weather encountered by the cruise ship 200 miles north north east of North Cape, New Zealand, resulting in injuries to 77 passengers and crew	30/07/08
2	Maersk Newport (No 13/2009)	Container ship	Investigations of Heavy weather damage 50 miles west of Guernsey and a fire alongside in Algeciras, Spain.	10/11/08 &

				15/11/08
3	Pacific star (No 5/2008)	Passenger cruise ship	Heavy Weather Damage	10/07/07
4	Young lady (No 3/2008)	Crude oil aframax product carrier	Dragged her anchor off Teesport	25/06/07
5	Oriana (No 36/2002)	Passenger cruise ship	Wave damage	28/09/00

Appendix 3-1 ; Review of Human Reliability Analysis Models

HRA Technique	Author and Year	Domain Application	Model	Methodology	Strength	Weakness	Remarks
THERP	Swain, 1983	Nuclear Power Plant	$P(X/Y) = a + bP(Y/X)$	Define EOO & EOC and Recovery paths using ET. Uses NRC data base for P.	Model time and recovery paths. Good for procedural analysis	The model is based on cognitive errors, does not include PSF. Data limited to control room actions.	
SLIM-MAUD	Embrey, 1984	Nuclear Power Plant	Log Success P = aSLI + b Where; $SLI_i = \Sigma_j w_j R_{ij}$	Uses dependency model and Expert Judgement to allocate probabilities SLI developed by rating and weighing of PSF.	Flexible can be adopted for various applications with good theoretical background	Resource intensive. Sophisticated and requires calibration SLI	Training for assessors required
HEART	Williams J, 1990		Task-based HEP scale was	8-Generic task data reliability	Model EPC which are task	Task HEPs allocation	

			developed for assessor's guidance.	developed based on 38 EPCs.	dependent, quick and cheap quantification method.	for each task validation required.	
APJ	Kirwan et al., 1988			Description of task and estimation of HEPs.	Simple and constructive qualitative discussions possible.	Highly experienced expert required	
TRC	Dougherty, 1988		$T = \tau_R$ x τ_U Where; τ_R $[\tau.k_{c.}k_{psf} .l_R]$				
HRMS	Kirwan, 1997				Error reduction mechanism using PIF. Technique computerised to capture data.		
TRIPOD-Delta	Shell Petroleum, 1993-2002	Offshore Oil & Gas platforms	Philosophy based on accident forecast. Safety is forecast using General Failure Types (GFTs) not dependent on data.	Survey using plant personnel called Tripod sigma. It is a proactive technique.	Proactive and based on factual experience. Recognises individual descriptive risk perception.	Over reliance on personnel.	

Tripod-Beta	Same		Reactive investigation tool	Survey using expert investigation	Makes good recommendation	Reactive only	
CREAM	Hollnagel E, 1998		$R = [\sum_{Improved} + \sum_{Reduced}]^{-1/2}$ $MFR = MFR_0 \times 10^A$ for $0 < \theta < \pi/4$				
ATHEANA	Forester J, 2003		$P(HFE/S) = \sum P(EFC_i/S) * P(UA_i/EFC_i,S)$				
MERMOS	Meyer P et al 2007	Elecriccite de France	$P(HFMF) = \sum_{scenarios\ identified} P(scenario_i) + Pr$	Model emergency operating system failure			

Appendix 5-1: Qualitative Questionnaire

CODE	Human Performance Shaping Factor	Description	Score by Likert Scale How each of these factors can independently impact on crew performances.
A	Training	Training Includes:-On the Job and professional or routine for individual development on subject matter	
B	Welfare	Welfare includes: Individual hierarchy in the job, industry incentives available and remuneration	
C	Logistics	Logistics includes: company maintenance policy, availability of spares and tools onboard, manning levels, resource availability	
D	Crew Efficiency	Crew efficiency includes: individual background knowledge, skills and experience, health state, cultural and social status which influence performance	
E	Stress	Stress includes: Physiological: fatigue, hunger, pain, circadian rhythm and Psychological such as; a) Task speed/load b) Threats c) Sensory emotions	
F	Procedure	Procedure includes: Availability of standing instructions in normal and emergency operations. Also included are: list of adaptations, risks, test and alarm response systems.	
G	Communication	Communication includes; Signs and tags/level marks within systems, methods of crew feedback , language and documentation system	

H	Environmental effect	Environmental impact on crew such as: Motion sickness, noise, vibration, climatic condition etc.	
J	Supervision	Supervision indicates how closely crew are monitored, availability of help , discipline and safety culture implementation and monitoring-	
K	Others	Other factor of importance in human system interaction	

Appendix 5-2: Quantitative Questionnare

1. What is the level of personnel training on the job?

    a) Very Good (Above 90%)……………………………………………………………..
    b) Good (Above 70%)…………………………………………..…………….
    c) Fair (50%)……………………………………………………………………
    d) Poor [Below 40%]………………………………….................................

2. How is the Crew Welfare?

    a) Very Good………………………………………………………………….…..
    b) Good…………………………………… …………………………..…..
    c) Fair……………………………………………………………………….…..
    d) Poor………………………………………………………….…………….

3. What is the level of stress at sea (Average)?

    a) Very Tough…………………………………………………………….….…
    b) Tough…………………………………………………………….…………….
    c) Barely high…………………………………………………………………..….
    d) Low………………………………………………………………………….….
    e) Normal…………………………………………….,,……..…………….

4. How long is a crew (personnel) shift (watch) at sea is structured e.g. Rest hours over 24 hours?

    a) 10/24 hours rest……………………………………………………..…...
    b) 8/24 hours rest……………………………………………………….…..…
    c) 6/24 hours rest……………………………………………………………
    d) 4/24 hours rest………………………………………………………..….
    e) Others……………………………………………………………..……..

5. How do you punish or sanction personnel due to failures/breach?

    a) Dismissal…………………………………………………….…………….…
    b) Retirement…………………………………………………………….…..…
    c) Reprimand…………………………………………………….................
    d) Demotion/Fine……………………………………………………………....
    e) Others…………………………………………………………………………

6. How effective or strictly do you implement the crew annual leave roster?

    a) Over 90% compliance………………………………………………………….
    b) 50% compliance…………………………………………………………..…
    c) Below 40% compliance………………………………………………….…..
    d) 10% Compliance……………………………………………………………

7. How often to you enjoy annual leave?

    a) Yearly………………………………………………………………………...

b) Once in 2 years…………………………………………………………………
c) Once in 3 years……………………………………………………… …..……..
d) Others……………………………………………………………………….....

8. How will you rate environmental impact on average, (weather) on personnel performance at sea?

a) Severe…………(over 90%)……………………………………………………
b) Very tough…….(70- 90%)……………………………………………………
c) Significant……(50-60%)…………………………………………………..….
d) Fair……………(30-40%) ……………………………………………………..
e) Nil…… ………(less than 20%)………………………………………………..

9. How often does this kind of thing happen to you (environmental impact)?

a) Frequently per sail…………………………………………….……………..…..
b) Seasonally……………………………………………………………………….
c) Once per 5 voyages……………………………………..…………………..…
d) Once per 10 voyages…………………………………………………………….
e) Not significant…………………………………………………………………

10. Please answer Yes or No – "I do make mistakes on board" …………………………..

Yes ----------Due to (stress, weather, management influence, nature, boredom, etc

NO - Why (careful, good procedure, good design, comfortable……………………...etc

11. Rate as indicated the frequency, importance, or effort of memory phenomena.

a) Slip of action-How often does this kind of thing happen to crew at work?
b) Error proneness-Estimate the frequency of slips that occur during everyday life.
c) How often do crew make mistakes omission?

Appendix 5-3: Elicitation Results

Training	Welfare	Maintainance/Logistics	Crew Efficiency	Stress	Procedure	Communications	Supervision	Environment		Human Error
95.5	80.500	95.500	95.500	80.500	95.500	95.500	95.500	80.500		92.500
95.5	80.500	95.500	95.500	80.500	95.500	95.500	95.500	80.500		92.500
95.5	80.500	95.500	95.500	80.500	95.500	95.500	95.500	80.500		92.500
95.5	80.500	95.500	95.500	80.500	95.500	95.500	95.500	80.500		92.500
95.5	80.500	95.500	95.500	80.500	80.500	80.500	95.500	80.500		77.500
80.5	80.500	95.500	95.500	80.500	80.500	80.500	80.500	80.500		77.500
80.5	80.500	95.500	95.500	80.500	80.500	80.500	80.500	80.500		77.500
80.5	80.500	80.500	95.500	80.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	95.500	80.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500
80.5	80.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500

80.5	60.500	80.500	80.500	60.500	80.500	80.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	80.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	80.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	60.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	60.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	60.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	60.500	80.500	60.500		77.500
80.5	60.500	80.500	80.500	60.500	60.500	60.500	80.500	60.500		77.500
80.5	60.500	60.500	80.500	60.500	60.500	60.500	60.500	60.500		77.500
80.5	60.500	60.500	80.500	60.500	60.500	60.500	60.500	40.500		77.500
80.5	60.500	60.500	60.500	60.500	60.500	60.500	60.500	40.500		77.500
60.5	60.500	60.500	60.500	40.500	60.500	60.500	60.500	40.500		77.500
60.5	60.500	60.500	60.500	40.500	60.500	60.500	60.500	40.500		77.500
60.5	60.500	60.500	60.500	40.500	60.500	40.500	60.500	40.500		77.500
60.5	60.500	60.500	60.500	40.500	60.500	40.500	60.500	40.500		77.500
60.5	60.500	60.500	60.500	40.500	60.500	40.500	60.500	40.500		60.000
60.5	60.500	40.500	60.500	40.500	60.500	40.500	60.500	40.500		17.500
60.5	40.5	40.500	60.500	40.500	60.500	15.500	60.500	0.000		17.500

Appendix 5-4: Explication of HEBCs

HEBC	Latent Variables	Hypothetical constructs (abstract concept)	Reliability status	Definitions and remarks
Crew Quality Audit (CQA)	Knowledge			
		➢ Higher degree	Excellent (+ve)	Masters/Pg Diploma/PhD – level of education
		➢ Bachelors	V. good (+ve)	BSc/BA honours or Higher diploma – reasonably educated
		➢ Diploma/equivalent	Good (+ve)	Ordinary Diploma/ Higher school certificate/Trade
		➢ School Cert	Fair- nil	Basic school certificate
		➢ Nil	Poor (-ve)	Assumed only primary school level of education. The crew has no cognitive skills
	Skills			A measure of competent excellence in performance; expertness; dexterity acquired through experience
		Hazard Perception ➢ Realisation of failure ➢ Diagnosing capability ➢ First aid capability ➢ Reaction time		Operator level of hazard perception can be assessed by the assessor. Crew can be interviewed or from crews historical data e.g. valuable contributions made by the individual, reports, suggestions , foresight etc. are used for this judgement

		Experience (Yrs):		Points to be allocated according to crew year of experience as follows:
		➢ Over 7 - Very Good	+ve	High heuristic know-how. Crew has good sea experience and he can perceive what may constitute risk and has the requisite skills to prevent failure
		➢ 4 to 7 - Good	+ve	High heuristic know-how
		➢ 1 to 3 - Fair	0	Cannot be relied upon for risk appreciation
		➢ less 1 - Novice	-ve	Assumed the crew has no experience on risk perception
	Health state:			It is important that these assessments are made confidential
	Psychological	➢ Conscientiousness ➢ Openness ➢ Extraversion ➢ Agreeableness ➢ Neuroticism	+ve	Morale, emotions and mental stability of crew based on experience or as observed by the assessor
	Anthropometric	➢ Ability to Lift, haul, pull, rescue etc ➢ withstand Physical stress/fatigue-pain in	+ve	Anthropometric has to do with individual physical fitness to duty; agility, strength, built up, colds, influenza, gastro-intestinal upset etc. Ability to Lift, haul, pull , withstand Physical stress/fatigue-pain in : Damage Control & Fire fighting (DC/

		DC and FF ➢ Withstand sea state ➢ Mental balance		FF), ability to fasten/loose, rescue , withstand motion sickness
	Cultural/social status	➢ Sociability ➢ sports and recreation ➢		Level to which the crew mixes up (interactions), demographic and geography, trust, responsibility, etc.
		➢ Controlled drinking attitude ➢ Uncontrolled drinking	Nil -ve	Whether or not the crew gets drunk based on historical experience. Drinking habit be assessed on scale as it affects cognitive state
Training				Training includes on the job training and any other sub specialisation.
	On the Job Training (OJT)	Induction		Induction training is the basic operational routine training including systems safety issues
		Application		Application is advanced training for a particular plant/system after 6 months of induction training. It is system sub-specialisation e.g. refrigeration/AC
		None	0	Novice operator just joined the organisation and deployed to duty without formal induction nor application course is view as a potential risk.

	Crew Resource Management (CRM)			CRM -management course which makes optimum use of resources, equipment, procedure, personnel, risk perception and mitigation.
		CRM1		Designed to improve cognitive ability
		CRM 2		Management level training for interpersonal skills of personnel for operational management and safety.
		None	0	Novice or routine operator without CRM, no points earned.
	Professional			
		Specialisation		Specialisation in trade as marine operator e.g. STWC.
		Maintenance		Training on the user maintenance skills for the system in which he/she operates or on the equipment
		None	0	Routine operator that depends on OJT
Supervision				
	Proximity			Availability of supervision or how close is the operator/system is being monitored
		First line manager		Indicates if a superior /manager is available within the vicinity of crew duty post..
		Remote monitoring		Supervision by remote sensors/CCTV's etc

		Intermittent		Pop-up or intermittent supervision by superior or peer-.
		none	0	Operator is autonomous, self accounting
	Discipline			Management policy on punishment to crew irresponsiveness
		Very strict		Management is tough and punish offenders out rightly
		Moderate		Punishment in most cases is by reprimand
		loose	0	In most instances offenders are not punish.
	Safety Culture			Level of management ‘s commitment to safety
		Strict		Management has put in place dedicated safety checks mechanism and adequate resources made available. In some cases a dedicated safety personnel may be appointed.
		Proactive		All known and perceived failure modes adequately mitigated
		Reactive		Management is only reactive to failures
		Loose	-ve	Safety measures are neglected and no dedicated supervision in place
Logistics				
	Maintenance.			In house (operator maintenance scheme) improves

				crew knowledge, belonging and sense of duty.
		Repair		A situation in which crew are directly involve in maintenance, repair and calibration
		Servicing		When crew are involved in basic servicing, or operational tests only
		Contract/external servicing		When both repair and servicing works are contracted out
	Spares/tools			Availability of spares and tools for onboard or offshore repairs
		Spares/tools available onboard		When complete inventory of necessary spares and essential tools are borne on board e.g. servicing calibration , repair of essential defects and damage control/fire fighting.(DC/FF)
		Spares/tools by request		Spares and tools are supplied based on request.
		Spares/tools not adequate	-ve	When spares and tools are not available for servicing equipments. Crew struggle to manage
	Time/planning			Management/organisational ability to plan operations well ahead of time. Resources made available, system/ equipment put in operational state and personnel adequately prepared. This will eliminate last minute rush and reduce commercial pressure

		Very good scheduling		Resources adequate, material/ship/system and personnel well prepared and all departmental logistics supply on time.
		Fair scheduling	+ve	Logistics and preparation of system carried out at last minute
		Poor planning and scheduling	-ve	Commercial pressure heavy and to adequate time to meet up with logistics requirement as demanded by departmental heads.
	Manning			
		Adequate		When normal duty/watch periods at sea are 4 hrs on and 8 hrs off cycle is operated. This is the Navy standard.
		Average		When at least, 6 hrs on and 6 hrs off cycle is operated
		Below average	-ve	When 6 hrs on and 4 hrs off-duty schedule is operated or 8hrs –on /6hrs-off.
	Resource availability			
		Available		Adequate provision of all financial and material requirement for operation as provided requested by heads of departments
		Partially available		Situation when resources are partially made available and without reserve for emergency

		Poor	-ve	When operational resources (allocation) are denied or sub-standard items provided. Company reliance's on incrementalism is encouraged – additions and alterations becomes normalised without due diligence.
	Age of equipment			
		1 to 5 yrs		When the equipment is new and not more than five years in service from date of commission
		6 to 10		
		11 to 15		
		16 to 20	-ve	Degraded reliability
		over 20	-ve	When the system/equipment is old – over 20 years in service reliability is highly reduced.
Procedure				
	Standing instructions	Crew responsibilities		These are operational guidelines that specify crews responsibilities, safety instructions and overall conduct within the organisation
		Administrative procedures		Administrative procedure for operations, ease of communication, documentation and welfare
		Special instructions		These are safety tailored instructions either ; for emergency situations, information about existing and potential risks

		None	-ve	Situation where special instructions or crew responsibilities are not defined
	Normal operations			Operational Procedures – manual and instructions
		Stopping procedure		Imperative to define stopping procedure for all systems and equipments in use. The procedure must equally be displaced
		Starting procedure		Complete description of starting procedure for all operations – action, system or equipment must be defined and displayed
		Monitoring		Monitoring procedure and documentation of situation, action, parameter , supervision etc.
		None	-ve	Situation where start /stop , procedures are not available or when available are not complete
	Emergency operations			
		Stopping procedure		Emergency stop procedures
		Starting procedure		Emergency start procedures
		Monitoring		Emergency monitoring systems procedure
		Feedback		Emergency feedback procedure to command authority or superior
		None	-ve	Stop/start emergency procedure not defined
	Tests procedures (routine)			Availability of routine Pre-tests of equipment/ systems procedure – manual and calibration

				details
		Yes		Pre-start tests
		None	0	
	Alarm procedure			Procedures for acknowledgement of alarm /lights and feedback.
		Yes		
		None l	-ve	
Communication				
	System			Signs and tags are important sources of information in marine systems example of sign is direction of rotation, or opening of valve
		Adequate signs		
		Few signs		
		No signs	-ve	
		Adequate tagging		
		Poor tagging		
		No tagging	-ve	
	Transmission			
		Direct	+ve	Direct methods are better than indirect
		Indirect	+ve	
	Feedback			Feedback of information in the form of

				acknowledgement or sending report by whatever means
		Crew response index		
		- fast		
		- slow		
		Documentation of adaptations		Documentation of activities and incidences
		- yes, written	+ve	
		- yes verbal	+ve	
		- None	-ve	
	Language -crew relativity			In order to ensure good and effective information sharing
		Clarity - good	+ve	
		Clarity -poor	-ve	
	Shift handing over			Communication during taking and handing over duty
		Written procedure	+ve	
		Supervised verbal	+ve	
		Un-supervised verbal	+ve low	
		Casual	-ve	A situation in which watch is taken over without due diligence because of familiarity between in coming and handing over crew.

		In absentia	-ve	Crew handing over while the successor is not on ground
Welfare				
	Hierarchy			Crew position in the organisation
		Managerial		
		Supervisory		
		Ordinary crew		
		Novice/trainee		
	Job description			Individual type and nature of job whether is commensurate to crew status or below.
		Job commensurate to qualification		
		Deviation from status		
		Below status		Job/responsibility not commensurate to crew qualification
	Incentive			
		Tangible stimulus		
		Intangible stimulus		
		None	-ve	
	Remuneration			

		Adequate-above standard rate		
		Standard rate		
		Below standard	-ve	
		Constrained	-ve	
Stress	Physiological			Results in extended periods to recuperate in downtime or continual periods of duty beyond operators mandated duty time.
		Fatigue		Physical demands, output in a task or as dictated by operational situation or morale related (moodiness), diminished perception or skills.
		Hunger		May be due to changes to appetite, scarcity or work exigencies
		Pain		Due to overload, incapacitated, or emerging health state
		Circadian rhythm		Migration towards predominantly night operation with the concomitant impact of interrupted sleep pattern
		None	+ve	Freshly and sound or cannot be quantified
	Psychological			
		Task speed/load		Working under time pressure
		Task complexity		

		Threats		Worries about real or Imagined problem, (financial, ill health or operational situation)
		Not observed		Symptoms not observed nor assessed.
		Sound mind	+ve	Calm and composed crew
Environment				
	Motion sickness	Rough sea		
		Moderate		
		Calm sea	+ve	
	Noise			
		Machinery		
		Sea		
		Others		
	Temperatures/humidity			
		High		
		Moderate		
	Vibration			
		Machinery		
		Sea		
		Others		

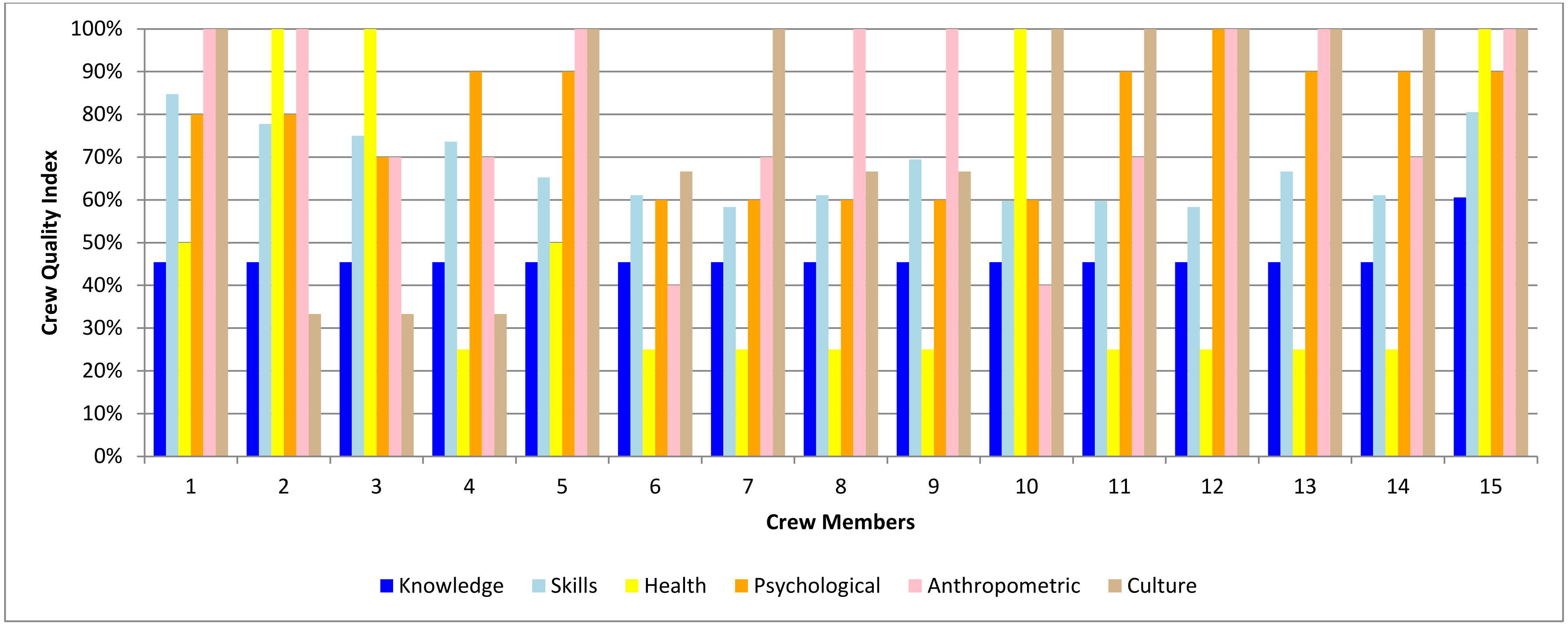
Appendix 7-1: HEBC Coverage’s in HRA Techniques

Serial	Type of HRA Model	Training	Welfare	Logistics	Crew Efficiency	Stress	Procedure	Communication	Supervision	Environment
1	CREAM	☑	-	☑ (preparation)	-	☑	☑	-	-	☑
2	ATHEANA	☑	-	☑ (plant - condition)	-	☑	☑	☑	☑	☑
3	SLIM	☑	☑	-	☑ (competence)	☑	☑	-	-	-
4	HRMS	☑	-	-	☑	☑ (task complexity)	☑	☑	-	-
5	STAHR –	-	☑	-	☑ (competence)	☑	☑	☑	-	-

6	HEART	☑ (Impaired knowledge)	☑	☑ (job aids)	☑ (individual factor-judgement)	☑	☑	☑	☑	☑
7	HFACS	☑	☑	☑ (inadequate resources)	☑ (physical, mental and physiological. Personnel readiness factor	☑ (physiological state)	☑ (organisational process)	-	☑	☑ (organisational climate)
8	J Reason 1997	☑	-	☑	☑	-	☑	-	☑	-
9	Tripod-D	☑	☑ (House keeping)	☑	-	☑ (incompatible goals)	☑	☑	-	-
11	MESH (Aviation)	☑	☑	☑	☑	☑	☑	-	-	☑

12	REVIEW (Rail problem Factors)	☑	☑	☑	☑	☑	☑	☑	☑	☑
13	Properties of job	☑	☑	☑	☑ (autonomy)	☑ (challenges)	-	☑	☑	-
14	SPAR-H	☑	-	-	☑	☑	☑	☑	☑	-
		Training	Welfare	Logistics	Crew Efficiency	Stress	Procedure	Communication	Supervision	Environment
	Score frequency	12	8	9	10	12	12	8	7	6

Appendix 8-2- Bar Chart representation of results on crew quality exercise



Appendix 10-1: Subject Questionnaire on Crew Opinion and Feelings on Stress/Fatique

Seria	Questiion	Response	Response
1	Do you seldom get stresses as a sailor	a. Yes b. No	
2	Please indicate the kind of stress(s) you go through as a sailor	a. Aches and pain b. Nausea/dizziness c. Moodiness d. Irritability/agitation e. Sleeplessness	
3	Please provide more information of sailor stress pattern	Please Answer each (a to g) a. Before embark onboard b. Onboard but before commencement of voyage c. Leaving harbour d. At sea e. Entering harbour of destination f. At harbour of destination g. Leaving harbour for next voyage	High – --------Medium –--------Low - --------Negligible ………………………………………………….. ……………………………………………………………………. .. …………………………………………………………………… … …………………………………………………………………… … …………………………………………………………………… …. ……………………………………………………………………

			….
4	Please indicate your general feelings on stress	a. I seldom feel distracted and moody b. I feel agitated and confused c. I become pessimistic d. I become more excited and at alert e. I feel neglecting my duties	
5	When is your best time onboard	a. At home port of first departure b. At instance of leaving harbour c. At Sea d. At instance of entering destination harbour e. At final destination harbour	
6	How does stress pattern looks like at sea	a. Constant form port to port b. Cyclic from watch to off watch c. Very irregular throughput voyage d. Regular and constant if no problem is encountered during the voyage e. Continue to rise until arrived at destination port	
7	Which of the following influence your stress tolerance	a. Supportive friends/companions b. I have a sense of control c. Knowledge of my job	

		d. Adequate preparations	
8	Please indicate when stress is most critical	a. At harbour before departure b. At port of arrival (destination)	
9	How can sailor stress be reduced or eliminated	a. By improving platform designs b. Increase manning on board c. By adequate voyage planning d. Others	
10	How does management policy/action impact crew stress	Highly/Fairly/Lowly/None	